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Massachusetts Institute of Technology

International Motor Vehicle Program

Engine Plant Study

Working Paper

Title: **Description Of Procedures In Automotive Engine Plants (ABSTRACT)**

Authors: Denis Artzner, Dr. Daniel Whitney

Date: October 1997

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ABSTRACT

1. Human resources

- For automakers, the total cost of paying average workers is around $40000 per year (mean value); the numbers range from $30000 to $60000 (except for a Central European facility where it is much lower). On average, direct pay is three times the amount of benefits. In general, worker qualification does not affect the benefits policy within an automobile engine plant.

- Overall, the average age of workers in engine plants is slightly above 40 years old. There is no difference by geographic region. In older engine plants, workers do tend to be older. Annual turnover rates are around 5%. Mean values for unionization levels are 79% for hourly workers, 45% for salaried workers. It is common for production workers to be assigned different tasks; the engine plants where the union contract restricts the kind of activities are located in North America.

- A majority of engine plants surveyed have work teams, and they are deployed in all departments. In most cases, work teams were introduced about five years ago. Sometimes, work team leaders are not elected. The average training received is 41 hours per employee per year. Fluctuations in the values are large. European facilities tend to have more training. Respondents felt that inspecting one's work, being well trained, designing one's workplace and having suggestions accepted are factors which can help workers make high quality engines. Workers and management interact via meetings and surveys. There are usually fewer than 2 suggestions per worker per year. The more training people get, the more likely they are to make suggestions.

2. Logistics

- Delivery of parts to the *assembly* department of engine plants: the Japanese-owned facilities get a much higher fraction of these components delivered more than once per shift, compared to other plants. There are more instances of "just-in-time" practice for castings and parts delivered to the *machining* departments.

- Engine and vehicle assembly plants: for half of our sample, the average delivery pace of finished engines to the car assembly plant is once per shift or more frequently. Engine plants which deliver engines very frequently no matter how far their customer vehicle assembly plants are located. The average value of the average delivery size of finished engines is 273 units (the results are very variable, but in general, the more engines are produced per unit time, the larger the batch size). For one out of two engine plants, the average transit time to the customer vehicle assembly plant is less than half a day; however, there are many cases where finished engines are delivered to vehicle assembly plants located very far away.

3. Maintenance policies

- Total Productive Maintenance (TPM) is in place in all of the plants surveyed, but this is quite recent (implementation started between 1990 and 1994). In two out of three cases, it is based on a centralized planning and information system. All of the key maintenance items mentioned in the questionnaire are taken care of by all engine plants; however, the frequency at which maintenance is done varies a lot from plant to plant (average: one and a half times per week).

- Throughout all departments of engine plants, breakdowns are caused on average mostly by mechanical problems and then by electrical problems although there is a lot of variation between plants. For those types of failures, there is no link with any downtime statistics. Hydraulic failures occur more frequently in those plants which are older.

4. Production technologies

- Several of the engine plants surveyed are currently undergoing major changes. For a new engine variant, most engine plants can deal with the adaptation by using much more than half of the existing machines. In engine plants, a "minor upgrade" can stop lines anywhere between less than 24 hours to more than a week. Currently, assembly lines in engine plants can handle more flexibility than machining lines. When different engines are built in sequence, the pattern used most often is 1-1-1-2-2-2 (batch sizes range from 6 to 100's of engines).

- Current and future design and acquisition processes for equipment do not differ. There is one policy for the whole plant. For a majority of engine plants, the methodology is as follows: the automobile company takes care of defining the requirements, it has a large influence (along with an affiliate or sister company sometimes) for the planning process, but the design and building of equipment is done by an outside equipment or system supplier. Two areas where answers differ a lot concern the system integration and the actual installation of equipment in engine plants: in some cases, the automobile company is in charge, while in other cases, an outside firm does the job.

5. Quality

- Engines made in European plants have more complaints per 1000 than the North American or Japanese ones (caution: we have rather few of these data points from non-European plants). Engine quality as measured by complaints per 1000 units after engines are delivered: 3-month quality data are quite good predictors of 12-month data.

- In almost all engine plants, Statistical Process Control (SPC) data are collected and displayed at the line or work station. Engine plants also get back some engine performance and warranty data.

- In most instances, communication of engine design information is done via fax or hardcopy. Sometimes, CAD systems (mostly 2-D) are used to exchange design data; however, whether CAD systems are used or not, is not a function of the age of the engine plant or of the lines. In a majority of cases, the exchange of information between the plant and the engine design department take place weekly, with actual design changes happening monthly. On average, half of the design changes are due to the engine engineering department, in order to improve the engine and to fix design or performance problems. Other causes for design changes are the meeting market needs, fixing production problems, and responding to the evolution of regulations.

- All plants conduct hot testing of engines; in two facilities, only some of the engines are hot-tested. The test can last from 45 seconds to 18 minutes. The (few) all-aluminum engines of our survey are among those which undergo longer periods of hot testing. Less than 7% of the engines fail the hot test the first time. By looking simultaneously at the engine quality data and at the hot testing results, we did not find any correlation: hot test duration does not uncover problems which cause quality complaints 3 or 12 months after the engines are delivered to customers.

- According to our respondents, production technologies that can be critical for manufacturing high quality automotive engines concern machining operations more than the sub-assembly and final dressing of engines; interestingly, these technologies are most often supplied by outside vendors. In addition, organizational factors are seen as much more effective than automatization, in order to produce high-quality engines.

6. Information systems

- Information systems are in place in engine plants, and they are used quite extensively.

- While centralized systems tend to be used mainly for planning purposes, non-centralized computer systems can help compile some statistical data and tell about equipment problems. Rarely are information systems actually used to give work assignments to employees.

7. Accounting procedures and investment decisions

- For a series of recent major installations of equipment in engine plants, it took around two years between the approval of the plan and the moment when the first part was produced, and from there on, an extra three to six months for full production levels to be reached.

- The top financial indicator used by car firms for measuring the "performance" of engine plants is clearly variance from budget. Some financial ratios like return on equity or return on assets are not used at all. For non-financial indicators, the quality of engines is most important, followed by safety and environment concerns, logistical issues, and labor productivity.

- Product quality and internal rate of return are the two most important factors involved in engine plant investment decisions.

- Most common practice is that indirect cost allocation uses standard or actual labor hours.

- Activity-based costing systems were in place in 30% of the engine plants surveyed (1995 data).

8. Plant improvement efforts

- The persons surveyed do not think that more automation will be the key for progress in engine manufacturing. For the future, a strong desire is the ability to improve the flexibility of the factory, of the machines, and of the material flow. Interestingly, the respondents most interested by flexibility improvements are based in engine plants which currently deal with rather low levels of engine variety.

- On the list of factors which can help improve operations in engine plants, is the need to establish better contacts with people in the engine design department and with the suppliers of machinery. Also, being able to build more engines in less space is an important goal for several respondents; actually, those most interested by this issue are from engine plants where the utilization of space is already more efficient than on average.

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Introduction

Comments Relative to the Analysis of Part C from the IMVP Engine Plant Study Questionnaire.

Description of Procedures in Automotive Engine Plants

The goal of this working paper is mainly to communicate the information contained in Part C of the questionnaire about engine plants which had been filled out by the respondents of companies participating in the IMVP International Automotive Engine Plant Survey of 1995.

The topics covered are the following:

1. Human resources
2. Logistics
3. Maintenance policies
4. Production technologies
5. Quality
6. Information systems
7. Accounting procedures and investment decisions
8. Plant improvement efforts

Also, we wish to answer to some of the sponsors' strong desire to know what is happening in engine plants all over the world, in terms of plant procedures and organization. Obviously, the clients of this study who are operations people wonder what their competitors are doing, and this study can help them figure this out in some ways.

The abstract of this paper is a much shorter version of this document (it is like a 3-page "executive summary"), where the most striking findings are highlighted.

To those companies which have had some of their engine plants participate in the survey, we send along with this document a set of all the graphs and tables with the individual answers from the numerous charts which are inserted throughout this paper.

A few general remarks:

Please keep in mind that the information presented here is a "snapshot", because it only corresponds to what has been indicated to us by engine plants about their situation around 1995. This survey tries to capture how a series of engine plants operate; most of them are located in Europe and in North America (including one Japanese transplant); two are in Japan. More than 20 very different families of engines are manufactured in the facilities for which we have answers.

The data presented in the graphs and described in the text below can deal with answers to questions which all respondents might not have understood or interpreted in the same manner (especially in this third section of the questionnaire).

You will notice that in some instances, there are more answers than in other instances; this is because a few portions of the questionnaires were not filled out by some of the plants participating in the survey.

Some of the data from Part C had already been analyzed and shown via viewgraphs at earlier occasions during presentations to the sponsors of this IMVP study. A few results had also been included in Guillermo Peschard's Master's thesis at MIT (June, 1996), titled: "Manufacturing Performance: a Comparative Study of Engine Plant Productivity in the Automotive Industry".

1. Human resources

Annual pay of workers; direct pay vs. benefits

Two graphs are used to describe the results contained in Table C.1 of the questionnaire about the pay of workers in engine plants.

Chart 1.1 describes the companies' total annual cost of paying an entry-level, average, and experienced worker. Most of data points fall in the range between just under $30000 per year and $45000 per year (in two cases, the results are quite higher than this range of values, while in one other plant, the pay is much less, as it is a Central European facility). The graph also indicates in which region of the world the engine plants are located (E = Europe, NA = North America). The three engine plants operated by Japanese companies did not answer to this question. As an exercise, we mention the effect of the rise of the U.S. $ between 1995 and 1997 (average of +22% against the currencies involved in our sample): assuming no pay change in the engine plants, the salaries in 1997 $'s are plotted in the right columns. So, currency fluctuations and the resulting variations in the results plotted make it quite irrelevant to try to correlate pay numbers with other parameters or answers from the survey.

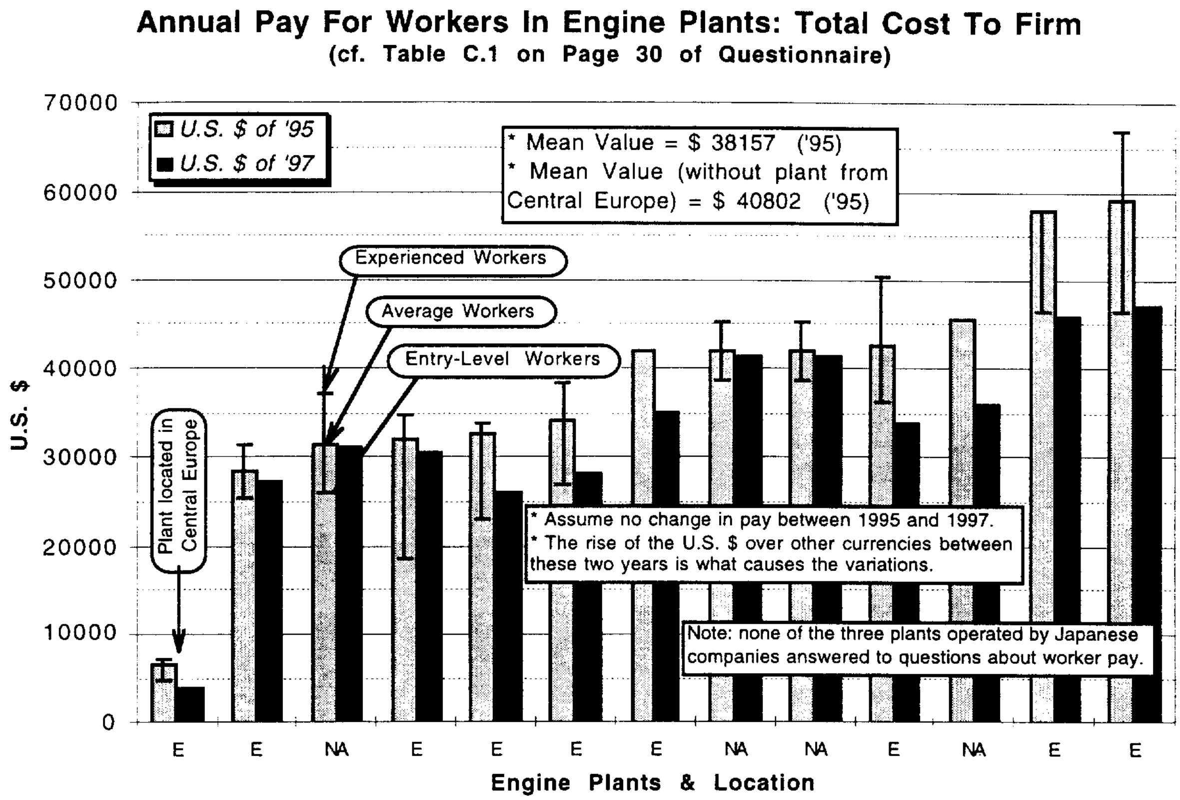


Chart 1.1

When the data were indicated by respondents (only 11 cases), we plotted on Chart 1.2 the relative distribution of direct pay versus benefits. On average, **direct pay is three times as much as benefits** (76% vs. 24%). We notice that the two engine plants where benefits (as a percentage) are greatest are located in developing countries. On the other extreme of the chart, the four engine plants where benefits (as a percentage) are smallest are located in countries from Northern Europe. We also note that, within an engine plant, the relative distribution between direct pay and benefits basically does not change whether one looks at entry-level, average, or experienced workers: salary policy is plant- and country-dependent more than it is a function of worker qualification.

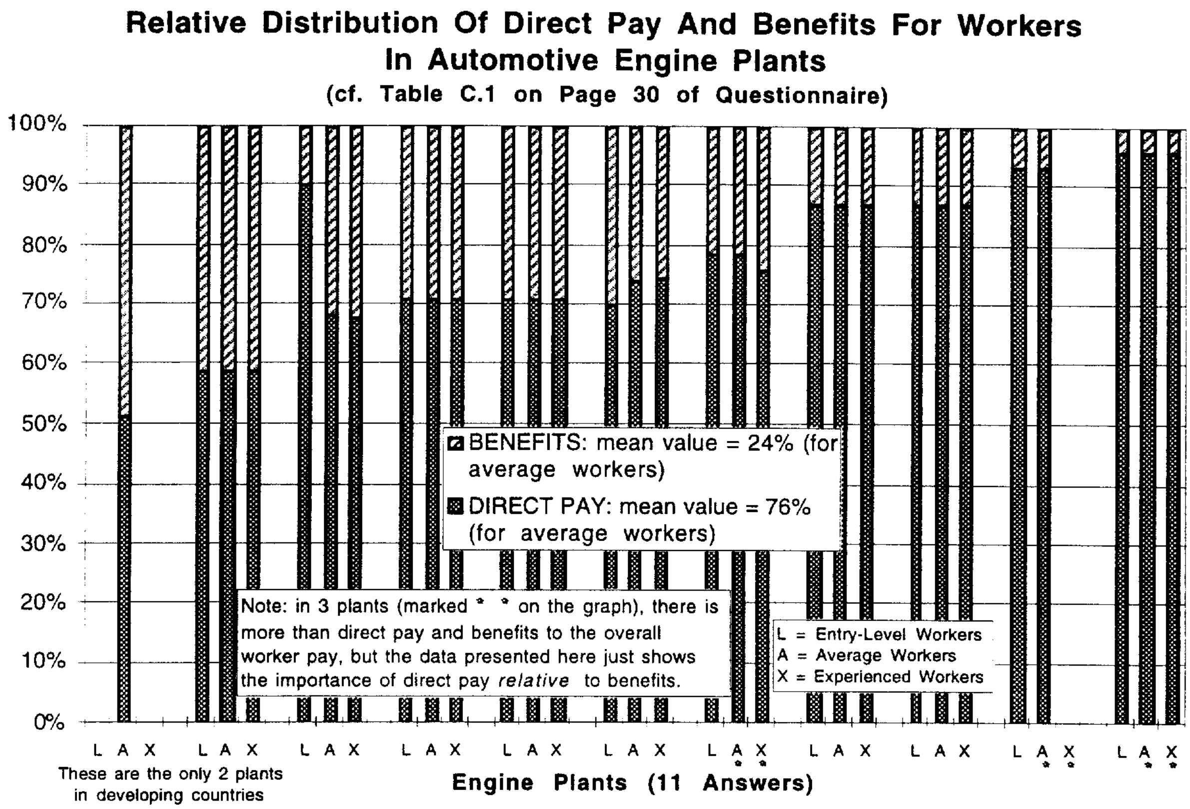


Chart 1.2

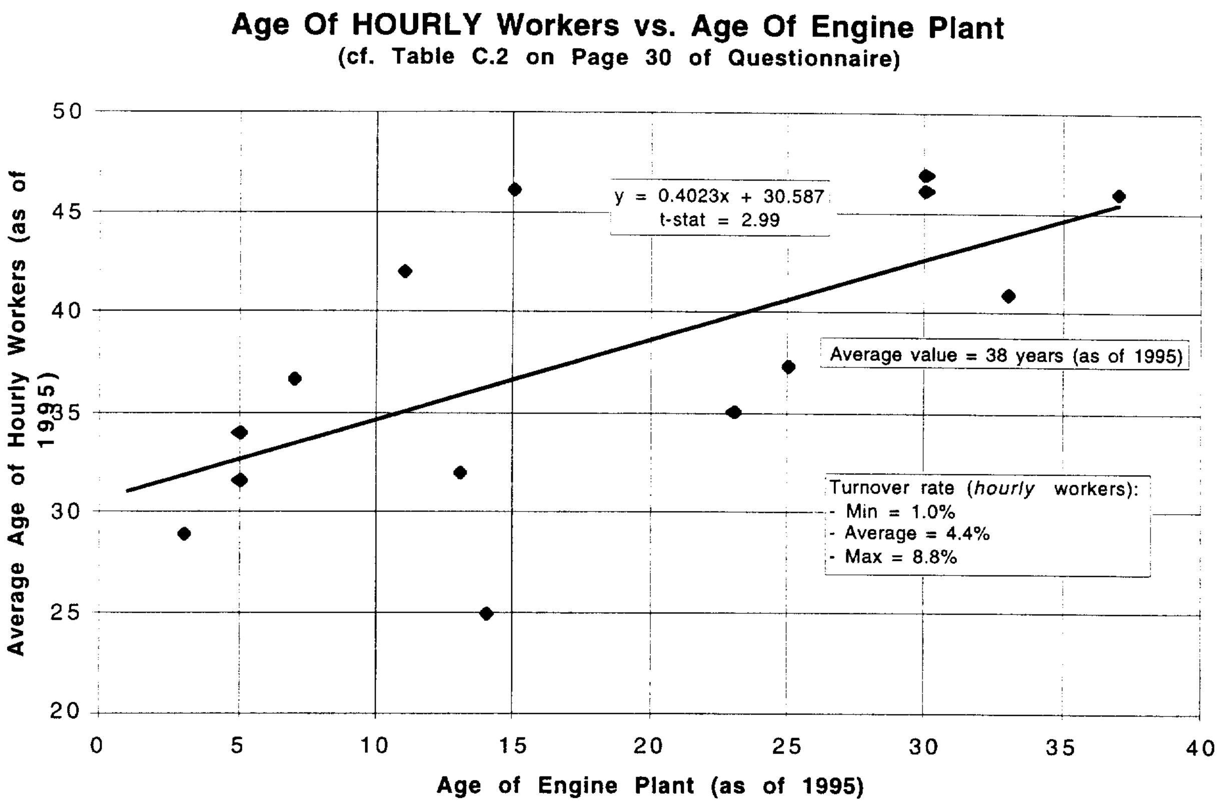
Age of workers, turnover, and unionization in engine plants

All of these data from Table C.2 of the questionnaire are shown on Table 1.1; they date from 1995 or just prior to that time. Since most of the engine plants from the survey are located in North America (NA) and in Europe, we have decided to give the specific numbers by region as well.

Table C.2 (cf. page 30 of questionnaire)								
Miscellaneous information about workers in engine plants (1995 data)								
Average age of workers								
	Hourly workers				Salaried workers			
	Average	Min	Max	Your plant	Average	Min	Max	Your plant
All	**38**	25	47		**41**	32	47	
NA	39	25	46		44	43	45	
Europe	37	29	47		41	34	47	
Annual turnover rate								
	Hourly workers				Salaried workers			
	Average	Min	Max	Your plant	Average	Min	Max	Your plant
All	**4.4%**	1.0%	8.8%		**4.3%**	0.0%	12.4%	
NA	3.2%	1.9%	5.0%		6.2%	1.5%	8.5%	
Europe	5.0%	1.0%	8.8%		4.2%	0.0%	12.4%	
Percent in unions								
	Hourly workers				Salaried workers			
	Average	Min	Max	Your plant	Average	Min	Max	Your plant
All	**79%**	0%	100%		**45%**	0%	100%	
NA	80%	0%	100%		6%	0%	11%	
Europe	78%	33%	100%		63%	0%	94%	

Table 1.1

Concerning the *average* **age of workers** (values vary around a mean of 40 years), there is no major difference between North American and European engine plants: the average, minimum and maximum values are quite comparable too. A question which then comes to mind is the following: does the age of workers have anything to do with how old the engine plant is? Chart 1.3 plots those two sets of values one against another, and from the statistical analysis, we can conclude that the age of engine plants and the average age of *hourly* workers are positively correlated. The same holds true (with slightly less statistical confidence) for *salaried* workers, as shown on Chart 1.4. So, **the older the engine plant, the older its workers** (on average).



Age Of HOURLY Workers vs. Age Of Engine Plant
(cf. Table C.2 on Page 30 of Questionnaire)
y = 0.4023x + 30.587
t-stat = 2.99
Average value = 38 years (as of 1995)
Turnover rate (*hourly* workers):
- Min = 1.0%
- Average = 4.4%
- Max = 8.8%
Average Age of Hourly Workers (as of 1995)
Age of Engine Plant (as of 1995)
50
45
40
35
30
25
20
0
5
10
15
20
25
30
35
40

Chart 1.3

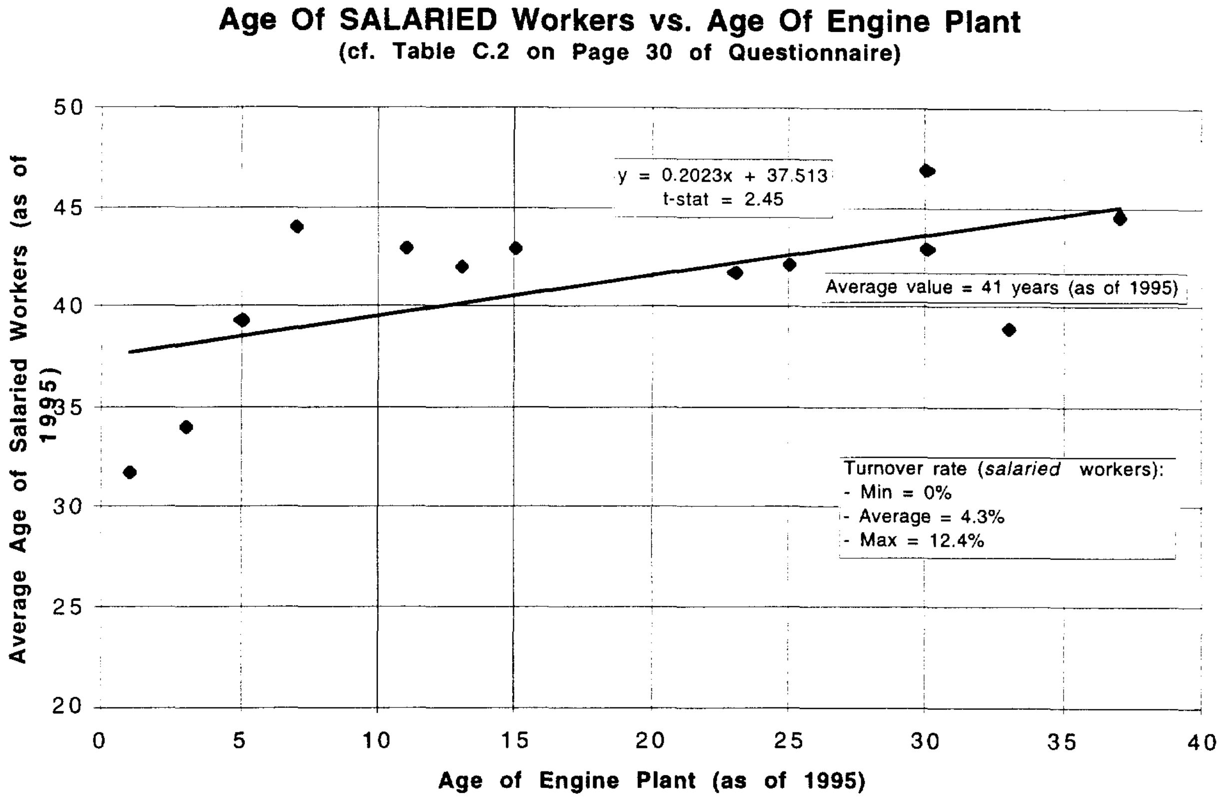


Chart 1.4

Annual turnover rates are almost always inferior to 10% -- typically, half of that. Table 1.1 enables to see the differences which exist between hourly and salaried workers, and between North America and Europe.

Hourly workers in engine plants are more **unionized** (average of 79%) than salaried workers (average of 45%). The details are indicated on Chart 1.5. There are some engine plants where all hourly workers belong to unions.

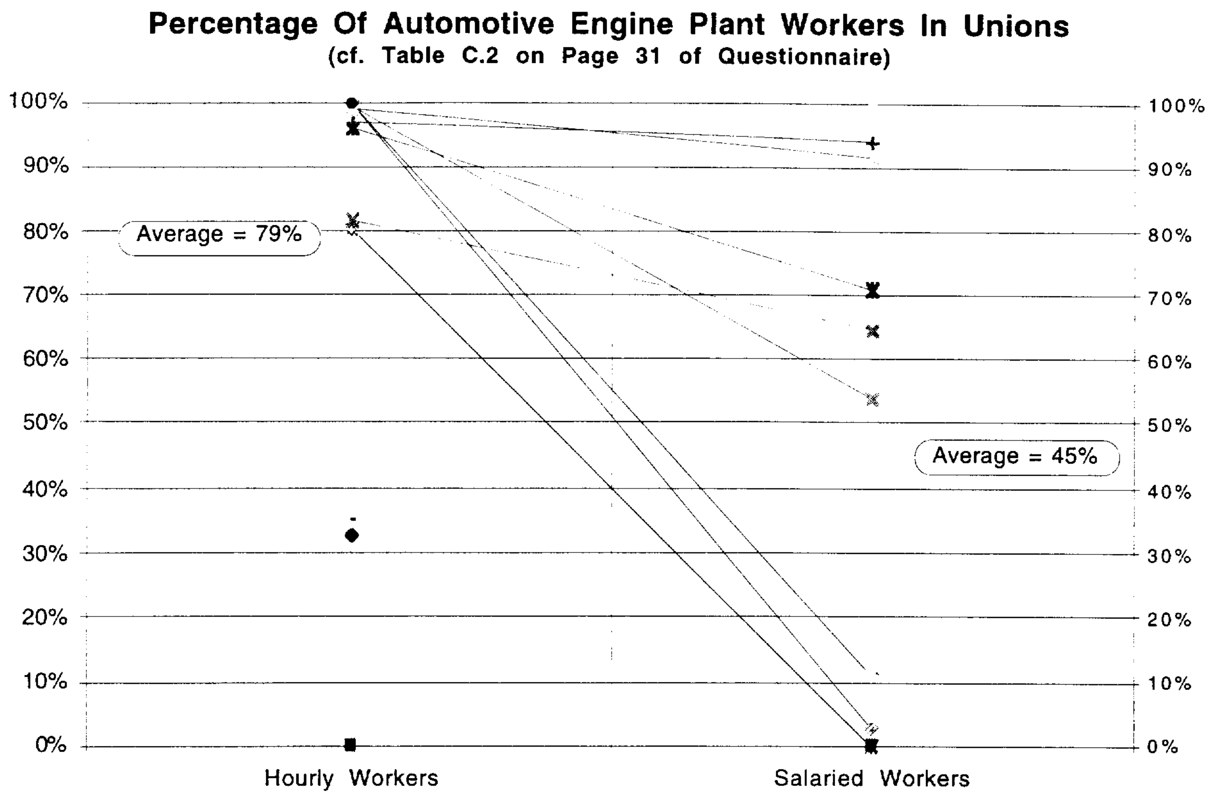


Chart 1.5

Non-production jobs performed by production workers?

Description of tasks

In Table 1.2, we present the answers from Table C.3 of the questionnaire. It indicates which duties can be performed by the different categories of employees within automotive engine plants.

Human Resources: Job Distribution in Engines Plants (cf. Table C.3 on Page 30 of Questionnaire)							
Question asked: who performs the following jobs?							
Duties — *Categories of employees* (Number of "*" = number of answers)	Production workers	Maintenance workers	Other hourly workers	Skilled trade	Supervisor	Engineering staff	Quality control staff
Adjust machines	* * * * * * * * * * * * * * * *	* * * * * * * * * * * *	*	* * * *	*	* * *	
Do rework or repair to parts and/or to assemblies	* * * * * * * * * * * * * * * *	* *	* *	* *	*		
Make minor repairs to machines	* * * * * * * * * * * * *	* * * * * * * * * * * *		* * * * *	*	*	
Set or adjust tools	* * * * * * * * * * * * *	* * *	* * * *	* * * *		*	
Sharpen tools	* *	*	* * * * * * * *	* * * * * * *		*	
Do preventive maintenance on machines	* * * * * * * * * *	* * * * * * * * * * * * * *	*	* * * * * *	*	* *	*
Inspect work, do gauging and measuring	* * * * * * * * * * * * * *	*	* * *	* * *	* *	* *	* * * * * * * * * * * * *
Record statistical process data	* * * * * * * * * * * * * * *	* *	*	* *		* * *	* * * * * * * * * *
Analyzes statistical process data	* * * * * * * * * *	* *	* * *	* * *	* * * * * * * * *	* * * * * * * * * *	* * * * * * * * * * * * * * *
Do material handling inside a shop	* * * * * * * * * * * *	*	* * * * * * *	*	*		*
Do material handling between shops	* * * * * *	*	* * * * * * *	* *	* *		*
Manage inventory	* * * * *	* *	* * * * * * *	* * *	* * * * * * * * *	* * *	*
Repair machines	* * * * *	* * * * * * * * * * * * * *	* *	* * * * * *	* *	* * *	
Note: it is possible that several categories of employees perform the same duty							

Table 1.2

Overall, one can notice that:

* Some categories of employees have job descriptions which seem to be well defined (e.g. maintenance workers, supervisors, and quality control staff people). For example, the quality staff will *just* be in charge of inspecting work, doing gauging and measuring, along with recording and analyzing statistical process data.

* On the contrary, **production workers are often assigned to a series of many different tasks** in engine plants. Also, other hourly workers and skilled trade people can have several duties.

* Aside from analyzing statistical process data, the engineering staff if not involved very much in the activities listed in this table. Nevertheless, it is interesting to note that, out of 16 engine plants, the 3 belonging to Japanese companies account for almost 40% of the cases where engineering people are doing some of the jobs listed (aside from analyzing statistical process data). Thus, we can imagine that Japanese "methods" encourage engineers to get more involved on the factory floor. It may be that some of this is due to the fact that Japanese companies tend to have fewer levels of hierarchy than European or American automakers, hence increasing the variety of activities which the engineering staff has to deal with.

Production workers

Chart 1.6 indicates the date when production workers started performing *non*-production jobs for the 12 engine plants where such things are possible. These 12 facilities comprise 11 engine plants where the union contract does *not* restrict the number of different types of work which hourly workers can perform, plus one plant which is not unionized and where it is OK for production workers to do non-production work occasionally.

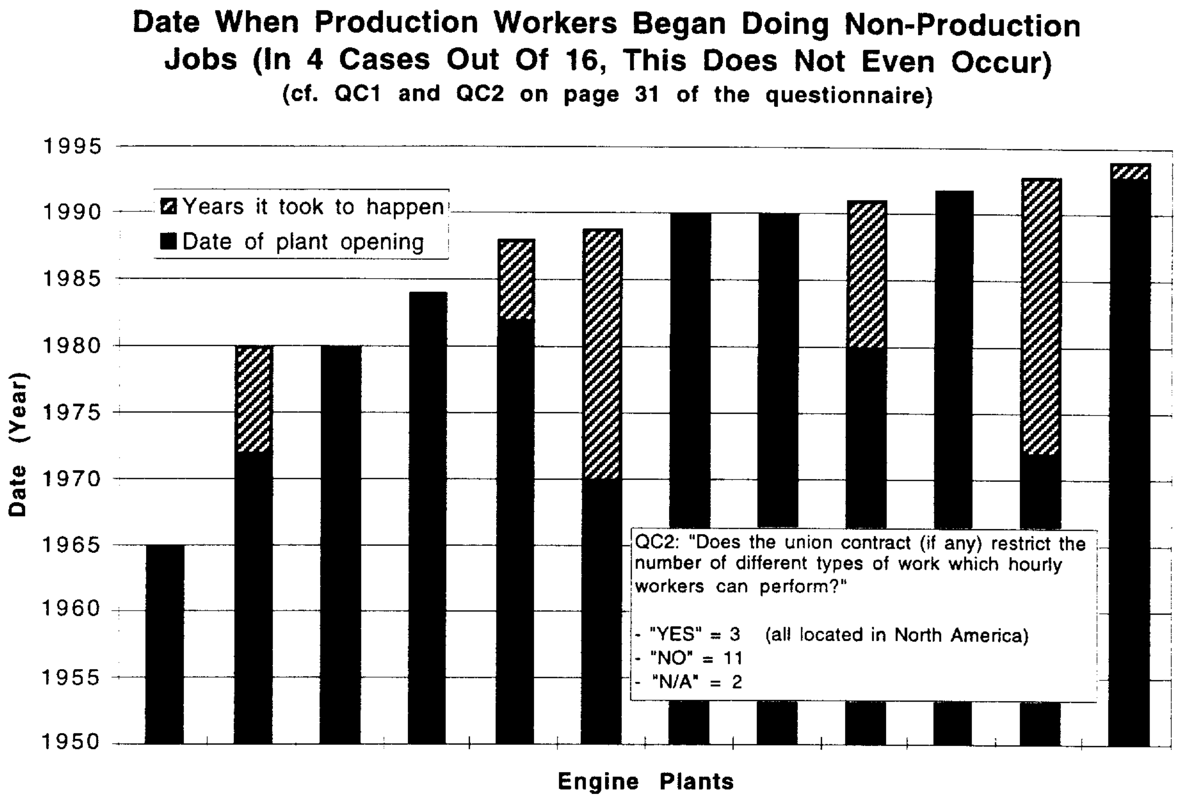


Chart 1.6

The 3 **engine plants where the union contract *does* restrict the kind of activities** which can be performed by production workers, are all **located in North America**.

On the graph, we have also indicated the number of years it took between the opening of the plant and the time when "work flexibility" began. In half of the cases, it was immediate, but in the other half, it took a long period to happen.

Quality circles in engine plants

Analysis of the survey shows that there are problem-solving groups (such as quality circles, Kaisen groups...) in all but one of the participating engine plants.

However, the extent to which these groups are deployed varies a lot from plant to plant: anywhere between 6 and 38 groups (for a majority of facilities), around 100 (two instances) or even many more (400 groups) in one specific engine plant (which is very large indeed). Chart 1.7 shows this.

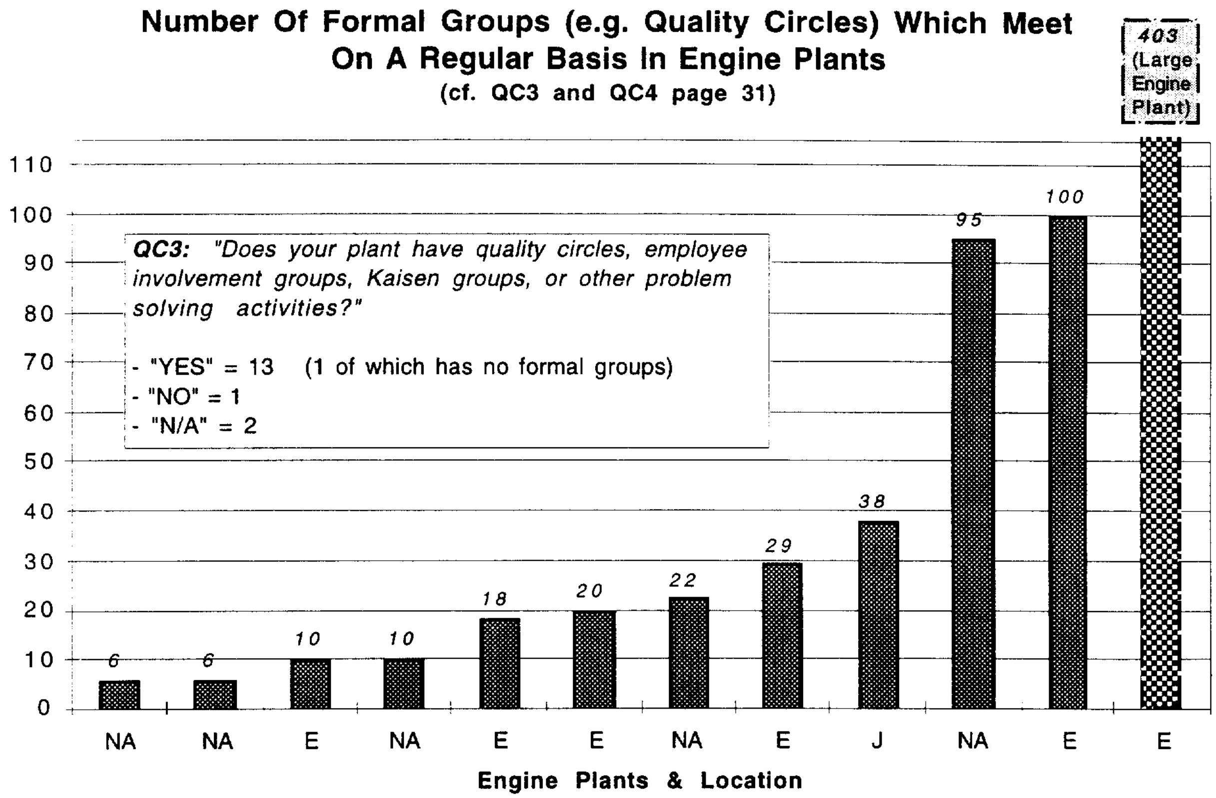


Chart 1.7

Work teams in engine plants

Among the engine plants which participate in this survey, only two had introduced work teams more than five years ago. The 10 others which do have work teams, have started this between 1991 and 1993. And when work teams were introduced in an engine plant, it was in all areas of the plant at the same time. **Work teams** within a department such as machining, subassembly or assembly and testing **always have a team leader**.

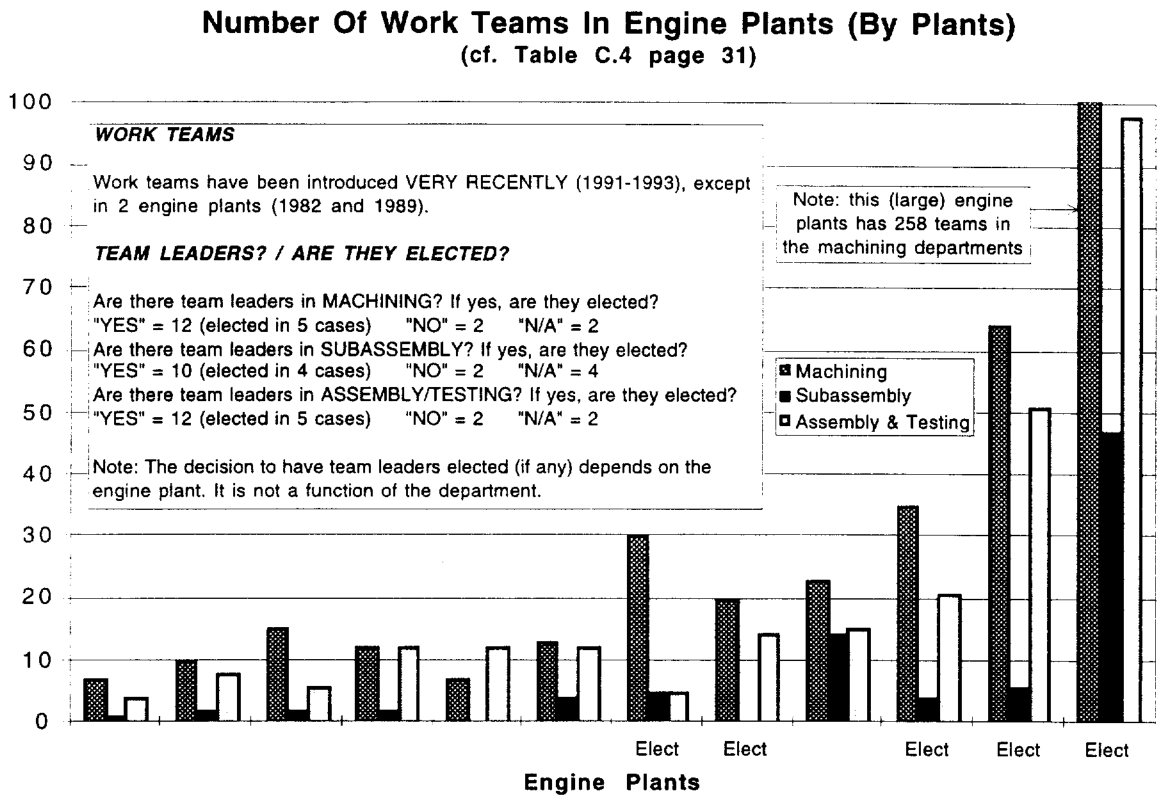


Chart 1.8

It is interesting to observe, though, that these team leaders are only elected in about one third of the cases. When team leaders are elected, they are elected no matter what part of the engine plant you consider. So, the decision about having work teams and electing team leaders depends on the engine plant, not on the departments within the plant.

Regarding the actual number of work teams existing in the various engine plants, these values are largely a function of the size and capacity of these facilities. For your information, we have plotted the raw data indicated to us by the engine plants. Do keep in mind, though, that the size of each work team can vary from one plant to another. We can conclude from Chart 1.8 and Chart 1.9 that there are almost always more work teams in machining than in other areas of engine plants like subassembly or assembly and testing. Some of this certainly has to do with the relative sizes of these departments.

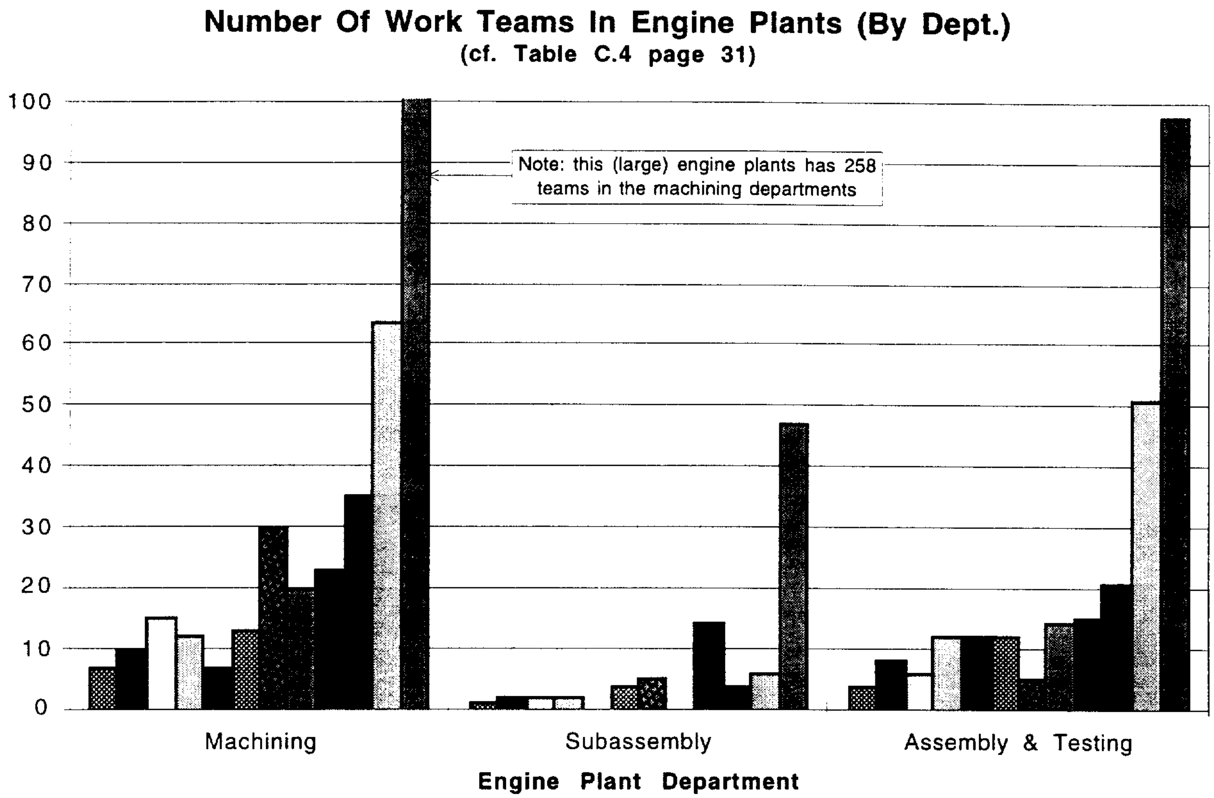


Chart 1.9

Training hours in engine plants

The **average** % values are given in a pie chart about training topics (cf. Chart 1.10). The percentages correspond to the average of 14 plants' respective distribution of time spent by topic.

Training Topics (% of Hours Spent: *Average* of 14 Plants)
(cf. Table C.5 on Page 32 of Questionnaire)

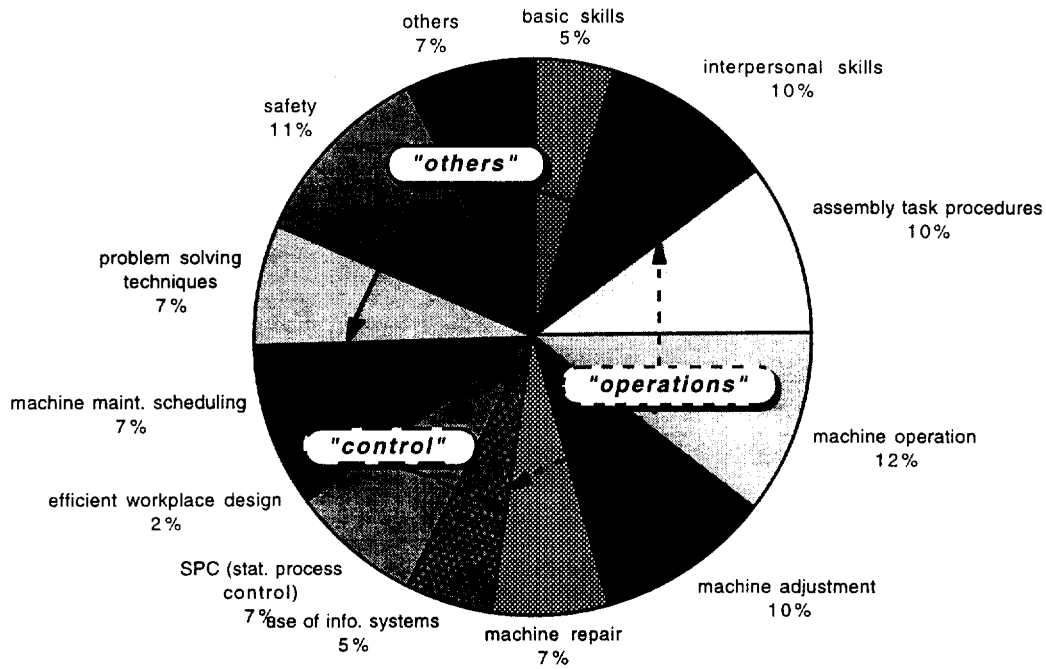


Chart 1.10

The following table is included so that you can realize how much emphasis can be given to a certain training topic: listed below are the **maximum %** of training hours spent on each topic by a plant; note that it is only a percentage value. Besides, within a plant, one can imagine that the amount of training focused on one particular subject may change a lot from year to year.

Maximum % of training time spent on...
- Basic skills: 44%
- Interpersonal skills: 23%
- Assembly task procedures: 24%
- Machine operation: 19%
- Machine adjustment: 40%
- Machine repair: 23%
- Use of info. systems: 15%
- SPC (statistical process control): 20%
- Efficient workplace design: 12%
- Machine maintenance scheduling: 31%
- Problem solving techniques: 20%
- Safety: 40%
- Others: 26%

For every topic (except for machine operation), there is always at least one plant telling that they spend none of their training hours on this topic. In other words, the **minimum %** of training hours spent on any topic is 0% (except for machine operation, where it is 4%). Since there were many topics in the list, this is not surprising.

Chart 1.11 presents a much better picture of what is happening in terms of training in engine plants, because it indicates the *actual* number of hours of training an employee receives every year. For clarity purposes, we have divided the topics from the list into three major categories:

* "**operations**" correspond to tasks which are directly related to the production of engines along the machining and assembly lines (assembly task procedures, machine operations, machine adjustment, machine repair),

* "**control**" deals with topics which indirectly affect the manufacturing process (use of information systems, statistical process control, efficient workplace design, machine maintenance scheduling),

* "**others**" (basic skills, interpersonal skills, problem solving skills, safety, others).

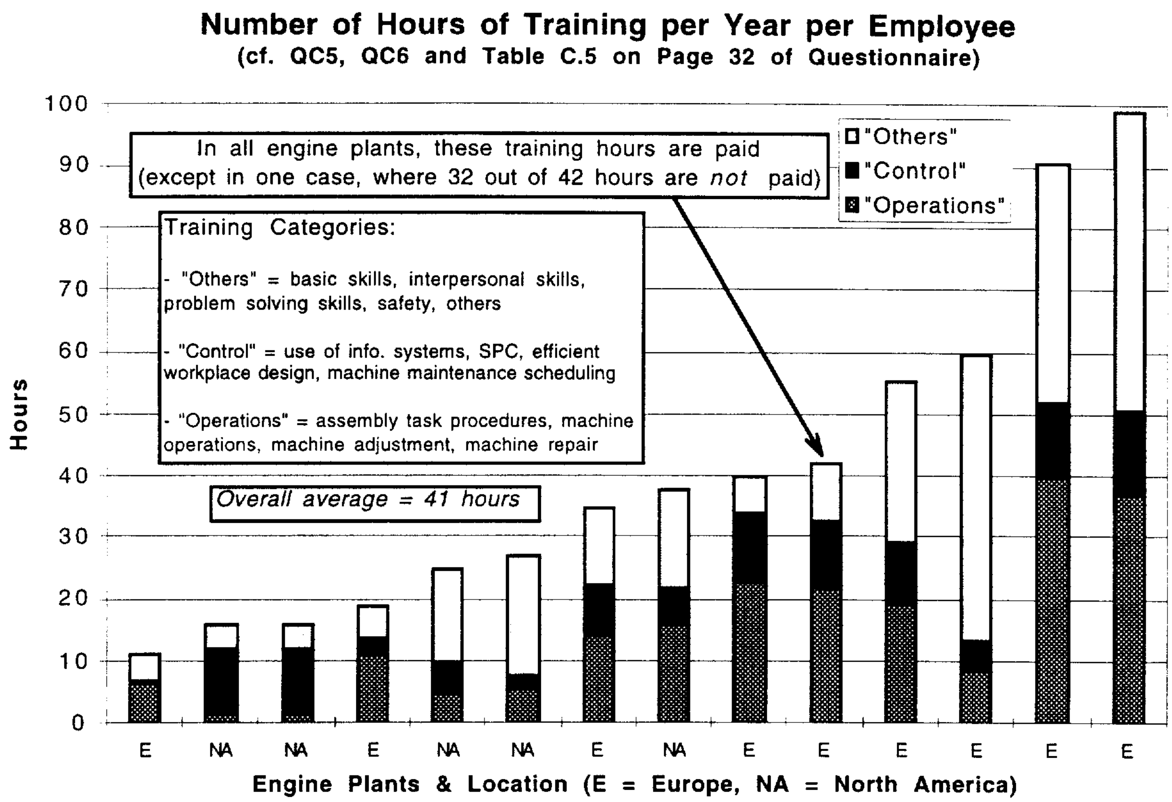


Chart 1.11

The main findings from Chart 1.11 are the following:

* Among the 14 engine plants for which we have answers about training practices, the *average* time devoted to training is **41 hours per employee per year**; this corresponds to a total of five days of work every year.
* The number of hours of training varies tremendously from plant to plant, ranging from 12 to 100 hours. Of course, these kinds of practices can very well change from one year to the next, so training should be a research subject which is investigated over a long period of time.
* Those plants which spend the **most** time on **training** are based **in Europe**.
* Also, the *way* in which training hours are spent differs greatly from plant to plant, as shown by the relative importance of the three categories of training topics on the bars of the graph ("operations", "control" and "others").
* The training hours which employees get are *always* paid for by their company, except in one engine plant where most of the training hours are not paid.

Factors influencing quality

This relates to the answers in Table C.6 of the questionnaire. It is important to note that the respondents were asked to evaluate the relative importance which several factors had on the *workers*, in order to obtain high quality engines.

Analysis Of Questionnaire (Part C): Table C.6 And Question QC7 (Pages 32-33)

Table C.6: *Question asked: "In your opinion, how important are the following to the workers in helping them produce high quality engines?"*

Factors Influencing Quality

(Number of answers = number of "")*	Very Important	Important	Somewhat Important	Not Very Important	N/A
Being on a team	*****	******	*	***	*
Inspecting own work	**************	*			*
Doing own maintenance	*****	*******	*	**	*
Being well trained	*************	**			*
Being on a union	**	***	***	***	*****
Not being on a union			***	*****	********
Taking part in designing the factory	*	******	******		***
Taking part in designing their workplace	***********	****			*
Being well educated	**	**********	***		*
Having suggestions accepted	********	*****	**		*
Monetary incentives connected to output	*	***	******	**	****
Others...	Very Important: Regular information and communication				
	Very Important: Managers' implication for product quality and diffusion of quality				
	Very Important: Detection of quality problems				
		Important: Continuous improvement groups			
		Important: Quality problems which cause rework			
		Important: Schedule flexibility for special occasions			

QC7: *"What methods are used by management to understand the workers' needs and motivations?"*

pulse survey
meetings
surveys, regular meetings
team meetings, TPM, suggestion system
yearly individual interview with level of hierarchy just above workers
annual interviews, monthly meetings, surveys
opinion surveys, round table meetings, phoneline/hotline and daily comm.
individual discussions manager/employee
workshops, plant meetings
management participation in group meetings, discussions with employees about of training and performance evaluation,...
... employees' ideas going to management via suggestion scheme, provide information to employees (various means), employee involvement in workshops and meetings, etc
meetings, workshops and mailbox

Table 1.3

As shown by Table 1.3, for the people surveyed, those factors which are the **most influential** for workers to help them produce high quality engines are:

* inspecting one's work
* being well trained
* designing one's workplace
* having their suggestions accepted

Then, a second category of factors came up as being quite important too. They are:

* team work
* doing one's maintenance tasks

We got mixed feelings about unionization and its "impact" on quality. Do keep in mind that, except for one case, all the engine plants answering to these questions have a large proportion of unionized workers.

Regarding workplace design, a vast majority of respondents from the engine plants told that it is "very important" or "important" that workers take part in "designing their workplace". It is thus a bit strange to see that in *some* of these same plants, the plant personnel is involved very late in the sequence of events in engine and plant design (as indicated by the data from Table C.17 which was included in the presentation made in Paris in October of 1996). Maybe that some of this has to do with the interpretation of the categories "taking part in designing the factory" and "taking part in designing their workplace" for the effect on quality. Nevertheless, one of the numerous lessons which came up from the study of lean production is that efficient use of work space can matter a lot (for example by helping reduce the amount of time spent moving parts around).

Interestingly, according to our respondents, monetary incentives for workers which would be connected to the output, do not appear to have any expected payoff in terms of quality. Some reasons for this might be that:

1. Such methods have been experimented and they have not been too successful.
2. On an individual basis, one worker in a large plant has almost no impact on the overall output of engines.

Nevertheless, it would be interesting to have the opinion of the workers themselves about this issue!

There are factors which were not listed in the questionnaire and which some companies thought had an important impact on quality; this is why we have indicated them at the bottom of the table of results under the category "others" (cf. Table 1.3).

Methods used by management to understand the needs and motivations of workers

By going through the answers, it turns out that **meetings** with workers, and internal **surveys** addressed to them, are common practice in automotive engine plants, in order for management to get an idea of what workers' "feelings" are. These interactions appear to be organized more or less rigorously. Besides, workshops can also be a way of sharing information and requests, which is probably less formal than meetings and surveys. We can also note differences in the frequency at which those events are scheduled. For more details, refer to the list of methods on Table 1.3 about QC7.

Remark: one answer to question QC7 mentions a phoneline/hotline as a means of communication between management and workers. Very recently, Continental Airlines has been an example of a highly successful company turnaround. Among different ways to achieve a high level of employee motivation and participation in the success of their company, there are toll free phone numbers which anyone at Continental can call in order to send comments or suggestions, and in order to know the firm's stock price or to get a weekly update from the CEO. Another practice learned during this transformation of the company and that was greatly emphasized by the CEO was that it is extremely wise to have people **focus on a few key metrics of performance**; the tough part is to determine which metrics to pick. It is known that people do pay attention to operating performance factors which are measured and tracked over time. One ought to keep in mind that, within large organizations like engine plants, all workers obviously do not react identically towards improvement, because they have a different opinion about the real benefits which the success of their firm can bring to them.

Suggestion policies, incentive programs, kind of information about performance which is available to the workers

In all but one of the 15 **plants** for which we have answers, a formal **suggestion program** has been **adopted**, and performance is regularly evaluated (question QC8).

Answers to question QC9 show mixed results concerning outstanding work awards; however, in a vast majority of engine plants (12 out of 15), special recognition awards are in place as part of incentive programs for workers. Performance is evaluated on a regular basis in almost all plants.

GRAPH: Average Number Of Suggestions Per Worker Per Year
INFO: About Incentive Programs And Information Flows
(cf. QC8, QC9 and QC10 on Page 33 of Questionnaire)

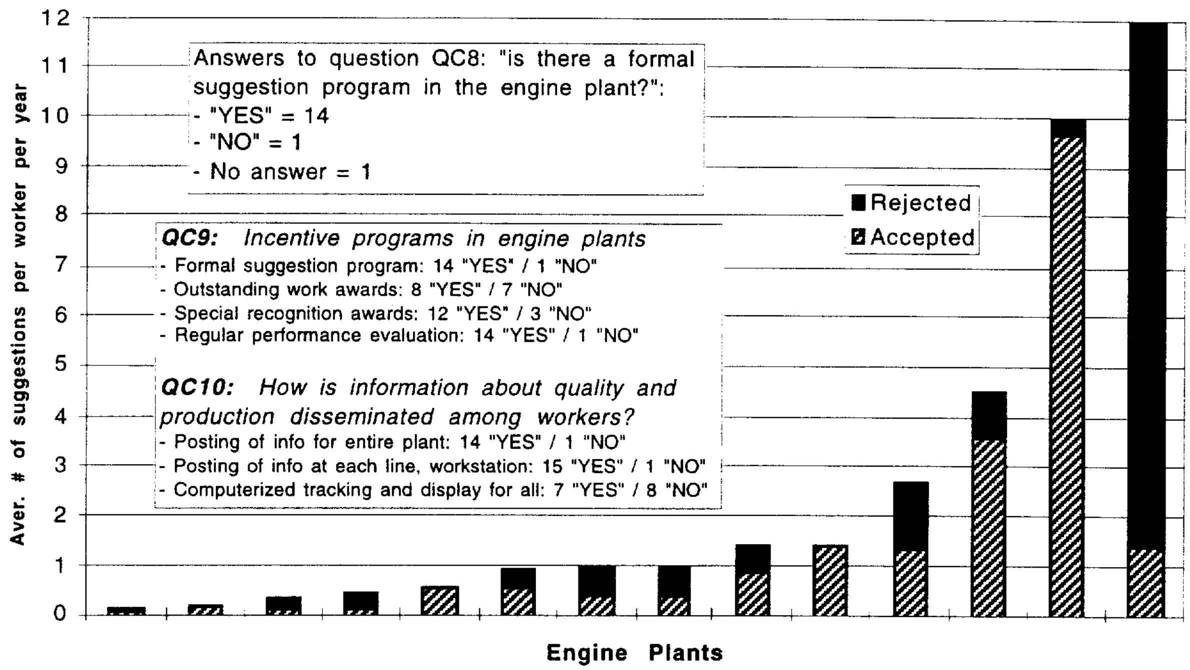


Chart 1.12

The average number of suggestions per worker made in a year ranges widely, from about 0 to as many as 12 suggestions. Actually, Chart 1.12 shows that there were three groups of engine plants, in terms of worker suggestion results:

1. For the vast majority of engine plants (more than two thirds of those which answered), the average number of suggestion per worker is less than 1.5 per year. The rate of acceptation ranges between one third and 100%.
2. In two instances, workers make more than 10 suggestions per year, but in one case, very few are accepted while in the other case, almost all suggestions are accepted.
3. Two other engine plants yield answers where workers make, on average, between 2.5 and 5 suggestions per year. In these two plants, more than half of the suggestions are accepted.

Information about quality and production is systematically *posted* in the facilities, whether it is overall plant data, or information specific to a particular workstation or line within a department. However, less than *half* of the engine plants say that they have a *computerized* tracking and display system which can disseminate information about quality and production for all employees.

Is there some link between training and suggestion practices?

We have plotted on Chart 1.13 the number of suggestions versus the amount of training, in order to see if there is any correlation between these two factors (we skipped two data points where the average number of suggestions per employee per year is very high compared to the rest of the dataset). Statistically, we are confident that more suggestions go on a par with a greater amount of training received. In other words, results from our sample suggest that, **in general, the more training hours employees get, the more suggestions they make**. An explanation for this could be that in plants where more training takes place, the employees feel that their company cares more for them, and their awareness translates into a desire to improve operations, e.g. through the use of suggestion programs.

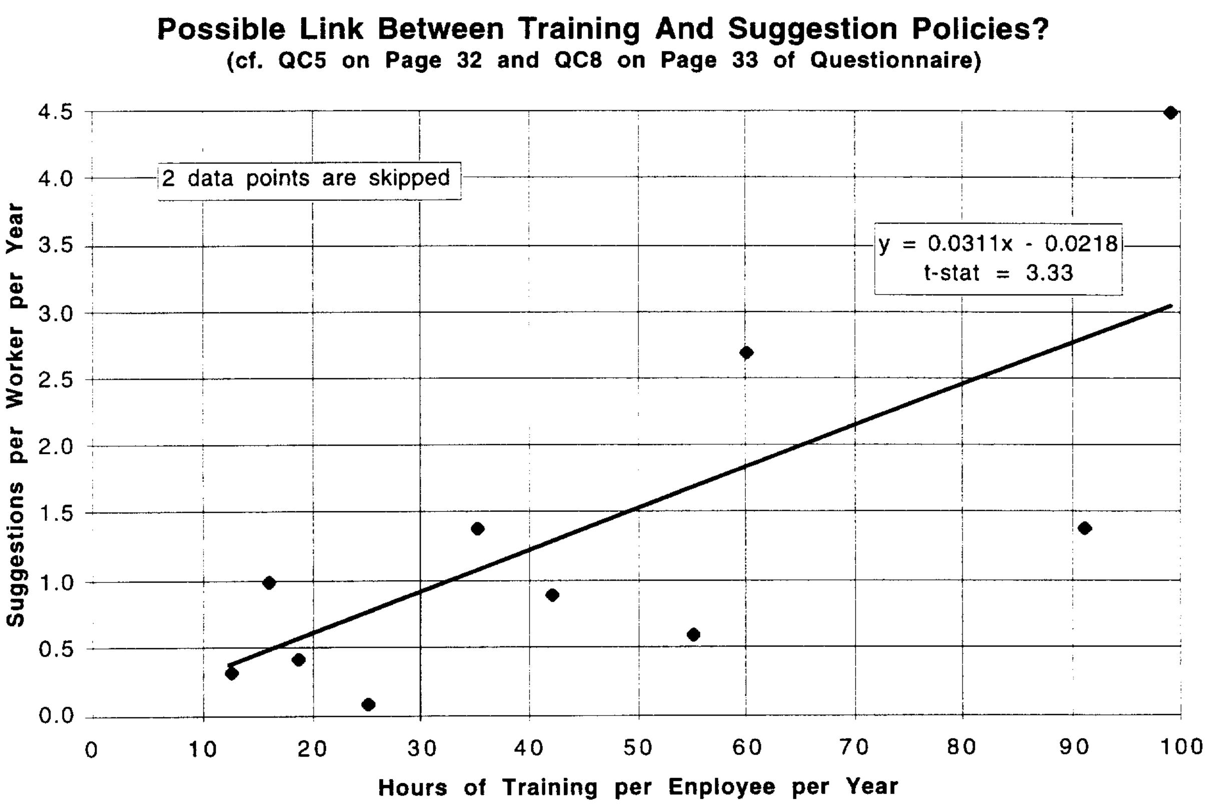


Chart 1.13

2. Logistics

This section deals with some aspects of logistics from Part C of the Engine Plant Study questionnaire which have not been communicated yet, such as transit times and lead times between engine plants, their suppliers, and the vehicle assembly plants. Inventory and work-in-progress data had been presented at earlier occasions such as meetings with IMVP sponsors.

Fraction of parts delivered more often than once per shift

Fraction of parts which are delivered to the **machining** department more than once per shift: average from our data = 39% (min. = 0%, max. = 90%). This mean value is way higher than for parts delivered to the assembly department. Some obvious reasons are that castings which will be machined constitute bulky, heavy, and rather expensive parts, so they ought not to be stored too long inside engine plants; thus, they tend to be delivered at a quite frequent pace. We wondered if there is any kind of difference between engine plants operated by Japanese companies and those from Western firms (European and North American automakers), but Chart 2.1 suggests there is no differentiation in the results, unlike what follows in the paragraph about parts delivered to the assembly department.

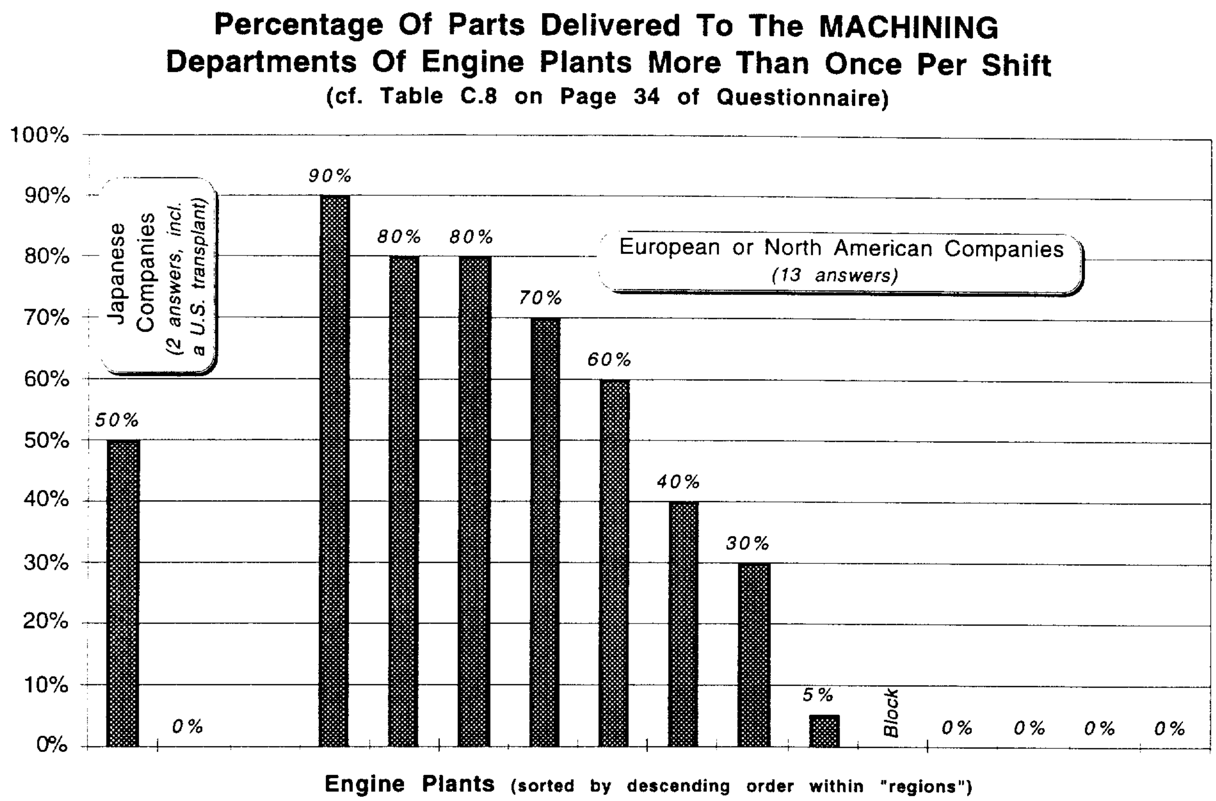


Chart 2.1

Fraction of parts which are delivered to the **assembly** department more than once per shift: average for the Japanese-owned engine plants which answered = 77%, while for all the others, it is only 3% of parts, on average (min. = 0%, max. = 10%)! This is a huge **difference between Japanese firms and Western firms**, in terms of delivery policy for those parts which are delivered more often than once per shift to the *assembly* department of engine plants. Even though we have few data points from Japanese companies, the striking contrast had to be pointed out. The data are plotted on Chart 2.2.

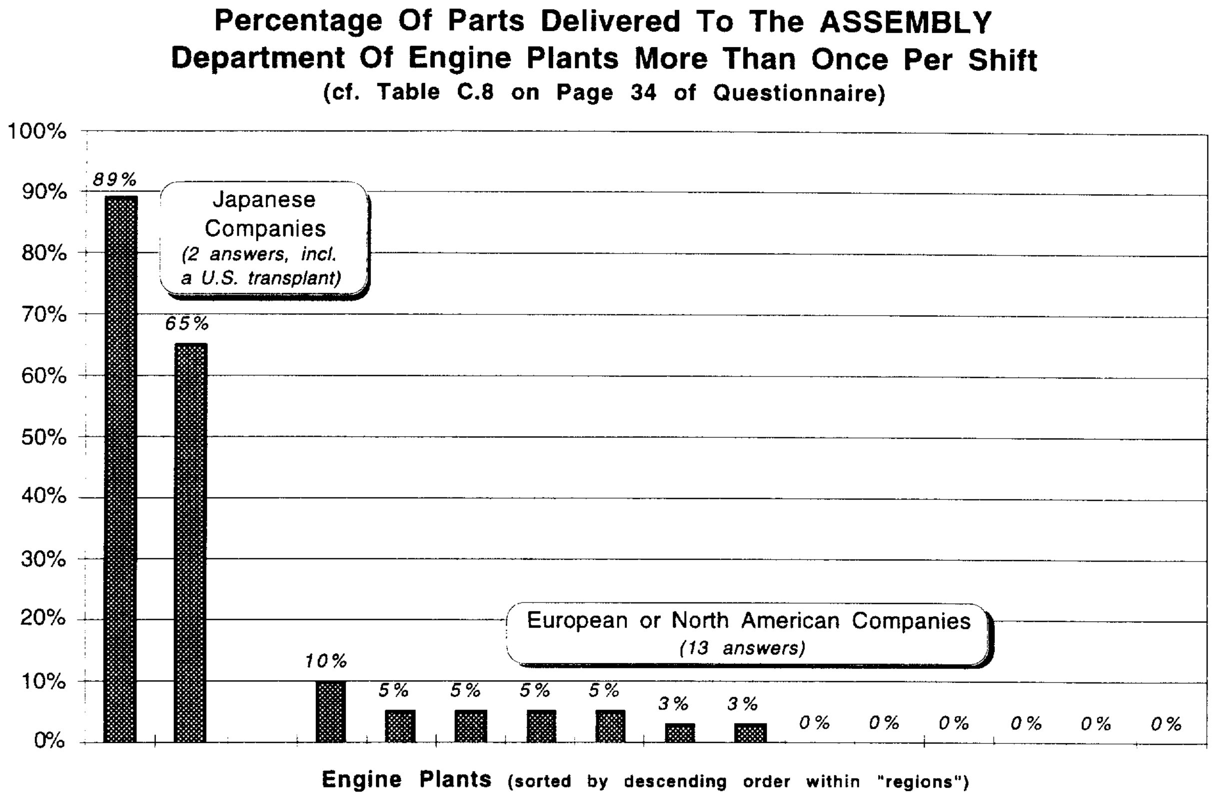


Chart 2.2

With Chart 2.3 and Chart 2.4, we want to see if a company which delivers a higher fraction of parts more often than once per shift to the machining departments of an engine plant also does so for the assembly department? Our survey suggests that it is not the case: even after removing the two data points from Japanese firms (cf. Chart 2.4), statistical analysis does not yield a strong correlation at all. It might be that a there is no such thing as a uniform delivery policy for parts delivered to the machining and assembly departments of engine plants, because these are two very different types of components in terms of weight, packaging, price, batch size, etc...

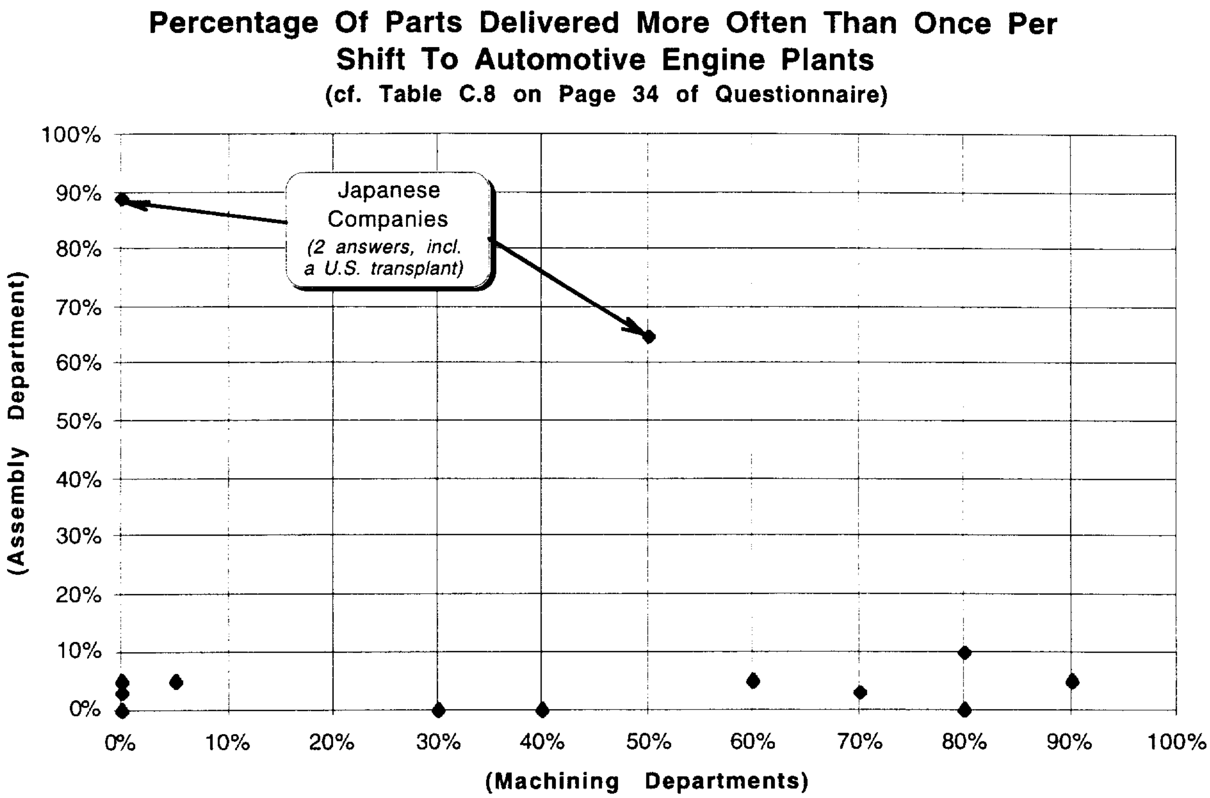

Percentage Of Parts Delivered More Often Than Once Per Shift To Automotive Engine Plants
(cf. Table C.8 on Page 34 of Questionnaire)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
(Assembly Department)
Japanese Companies
(2 answers, incl. a U.S. transplant)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
(Machining Departments)

Chart 2.3

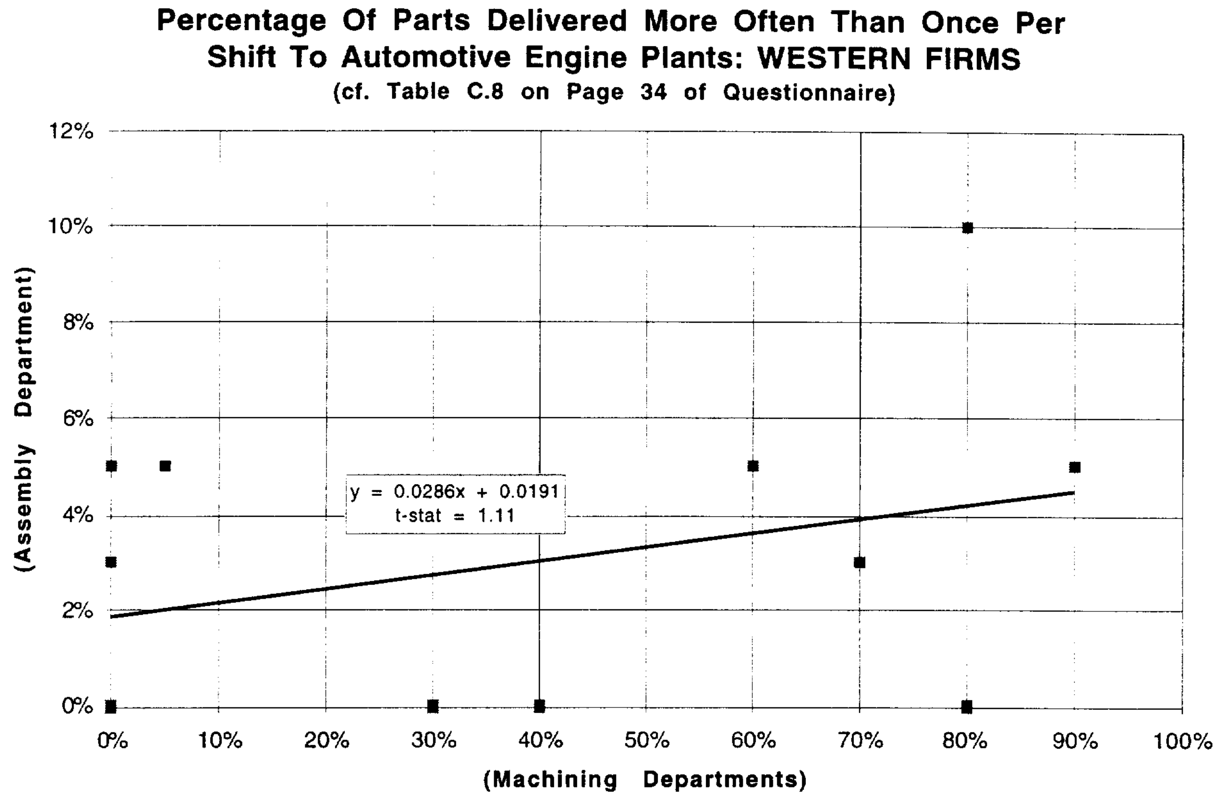


Chart 2.4

Transit time to the nearest and farthest suppliers of engine parts

The transit time data presented in the charts are separated in two categories: on the one side, components like castings which are delivered to the *machining* departments of engine plants, and on the other side, parts which are needed in the *assembly* department.

In the questionnaire, a distinction is made between those suppliers which deliver more often than once per shift to the engine plant, and the others. The answers comprise 18 families of engines. Let us consider the suppliers which deliver more than once per shift to the engine plants. It is interesting to note that these suppliers "exist" in only 8 cases when it comes to delivering parts to the *assembly* department, while there are 10 engine families for which suppliers deliver more than once per shift to the *machining* department. Parts like castings which are delivered to the machining departments can be quite bulky and expensive compared to components which are delivered to the assembly department of engine plants, so it makes a lot of sense to put more emphasis on just-in-time delivery methods for the parts delivered to the machining department. Because they are bulky, these parts cannot be delivered in batch sizes of large quantities; because they are expensive, the engine plant should not want to keep too many in inventory.

As shown later, there are some suppliers which deliver more than once per shift and which are located quite far away from the engine plant.

On the horizontal axis of both Chart 2.5 and Chart 2.6, the engine families are "ranked" according to increasing transit time between the plant and the nearest supplier.

On Chart 2.5 and Chart 2.6, the vertical scale indicating transit time is *logarithmic*!

1. Parts for the MACHINING departments (cf. Chart 2.5)

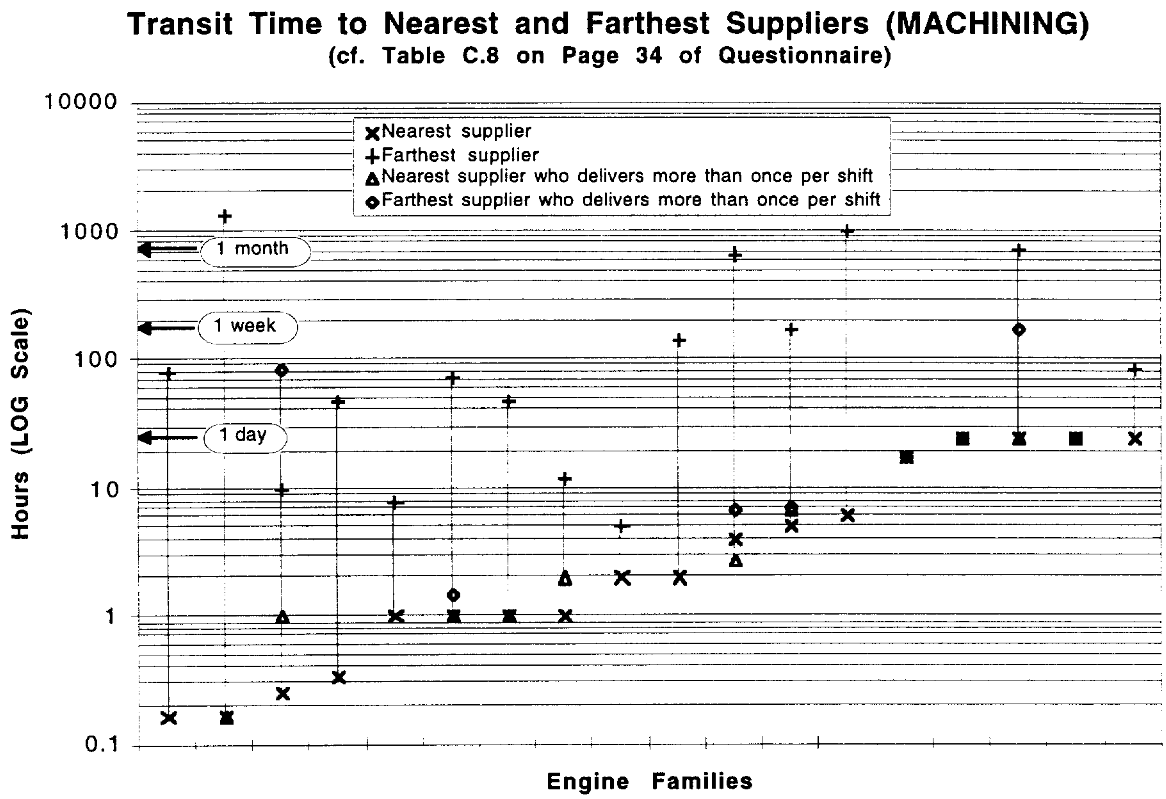


Chart 2.5

Out of 18 engine families made in the plants which answered to the questionnaire, 8 have their closest supplier to the machining departments at one hour or less of transit time.

Never does the closest supplier of components for the machining departments require more than one day of transit time.

Those plants which have their nearest suppliers extremely close to them do not necessarily have all of their suppliers very close, in terms of transit time.

In a majority of cases, the nearest casting supplier is one which delivers more than once per shift; we can imagine that logistics people have made sure that this would be the case.

Some engine plants have suppliers which are located very far away (cf. transit times of a month or more for the farthest suppliers in 4 cases).

However, for the suppliers which deliver more than once per shift (it is fair to say that they probably operate in just-in-time), the transit times are much shorter overall than for the other suppliers.

Do keep in mind that the questionnaire asked only about the closest and farthest suppliers; hence, only these extreme values can be shown on the charts.

2. Parts for the ASSEMBLY department (cf. Chart 2.6)

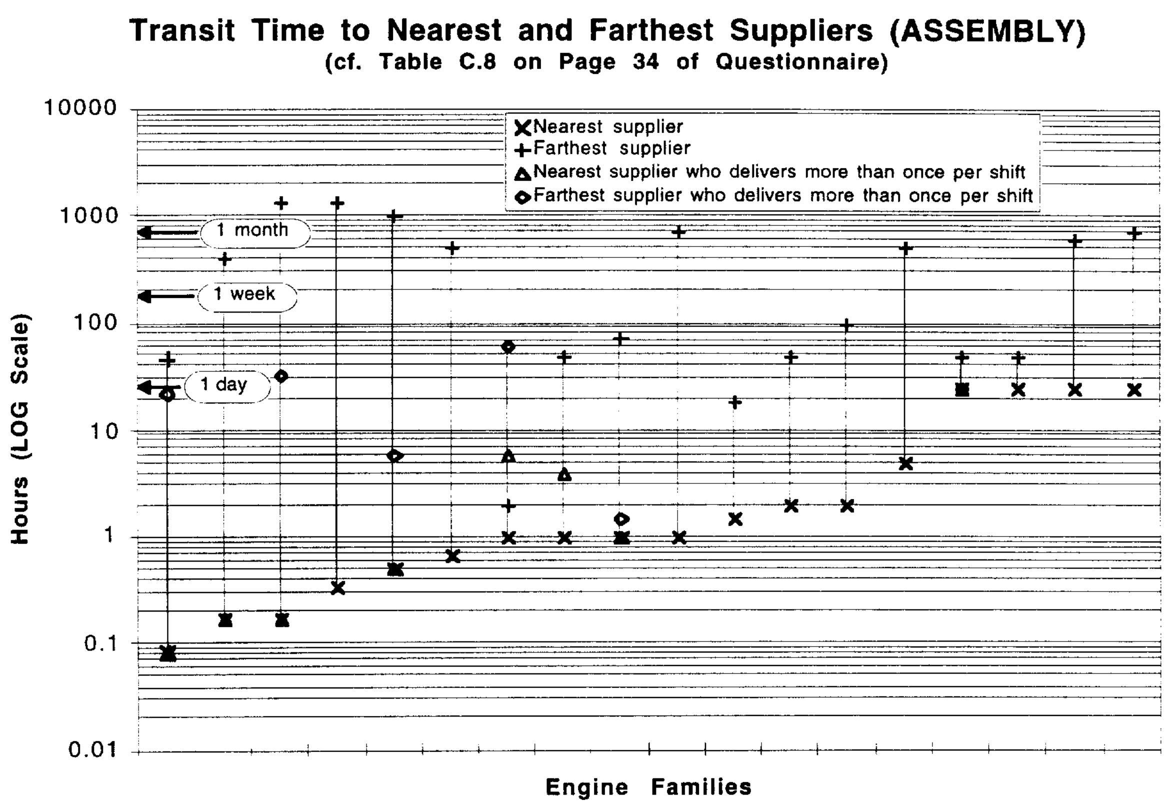


Chart 2.6

Before looking at the transit time numbers themselves, we should keep in mind that there obviously are more suppliers which deliver parts to the assembly department than suppliers which deliver parts to the machining departments of engine plants.

For suppliers of parts delivered to the assembly departments of engine plants, the closest suppliers which deliver more than once per shift are often separated from the engine plant by extremely short transit times: in 5 cases, less than one hour.

Even though the engine families of most engine plants surveyed (13 out of 18) had their closest parts supplier located less then two hours of transit time away, in 4 cases, one day of transit time was the minimum transit time.

Like in the previous section (machining department), those plants which have their nearest suppliers extremely close to them do not necessarily have all of their suppliers very close, in terms of transit time to the assembly department.

There are suppliers which deliver more than once per shift to the assembly department of engine plants, and which are located more than a day away (in terms of transit time)!

Do keep in mind that the questionnaire asked only about the closest and farthest suppliers; hence, only these extreme values can be shown on the charts.

Lead time between the suppliers and the engine plants

While the transit time discussed in the previous section is the time it takes to transport an item between the supplier and the engine plant, the *lead time* represents the actual time from the placement of an order to the delivery of the item to the engine plant. Respondents were asked to give their answers in one of five following categories of lead time values:

- '1' = continuously or more than once per hour (i.e. more frequent deliveries)
- '2' = two to four times per shift (using shifts of eight hours)
- '3' = once per shift
- '4' = once per day
- '5' = less than once per day (i.e. less frequent deliveries)

Horizontal axis: note that the engine families at the bottom of Chart 2.7 and Chart 2.8 do not match, because the ranking method used (by increasing average category number) might not give identical sets, and because we have 13 answers for the *machining* department data and only 12 for the data about deliveries to the *assembly* department of engine plants.

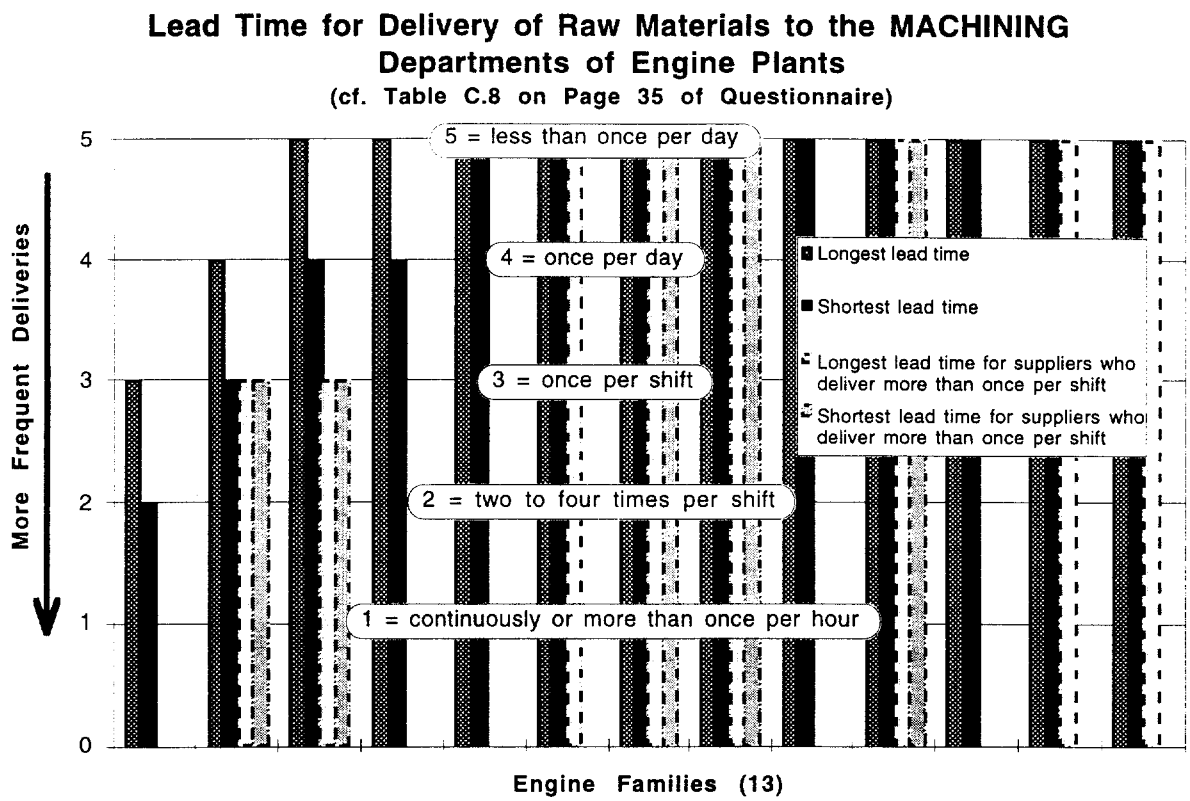

Lead Time for Delivery of Raw Materials to the MACHINING Departments of Engine Plants
(cf. Table C.8 on Page 35 of Questionnaire)
5 = less than once per day
4 = once per day
3 = once per shift
2 = two to four times per shift
1 = continuously or more than once per hour
More Frequent Deliveries
Engine Families (13)
0
1
2
3
4
5
Longest lead time
Shortest lead time
Longest lead time for suppliers who deliver more than once per shift
Shortest lead time for suppliers who deliver more than once per shift

Chart 2.7

Lead Time for Delivery of Parts to the ASSEMBLY Department of Engine Plants
(cf. Table C.8 on Page 35 of Questionnaire)

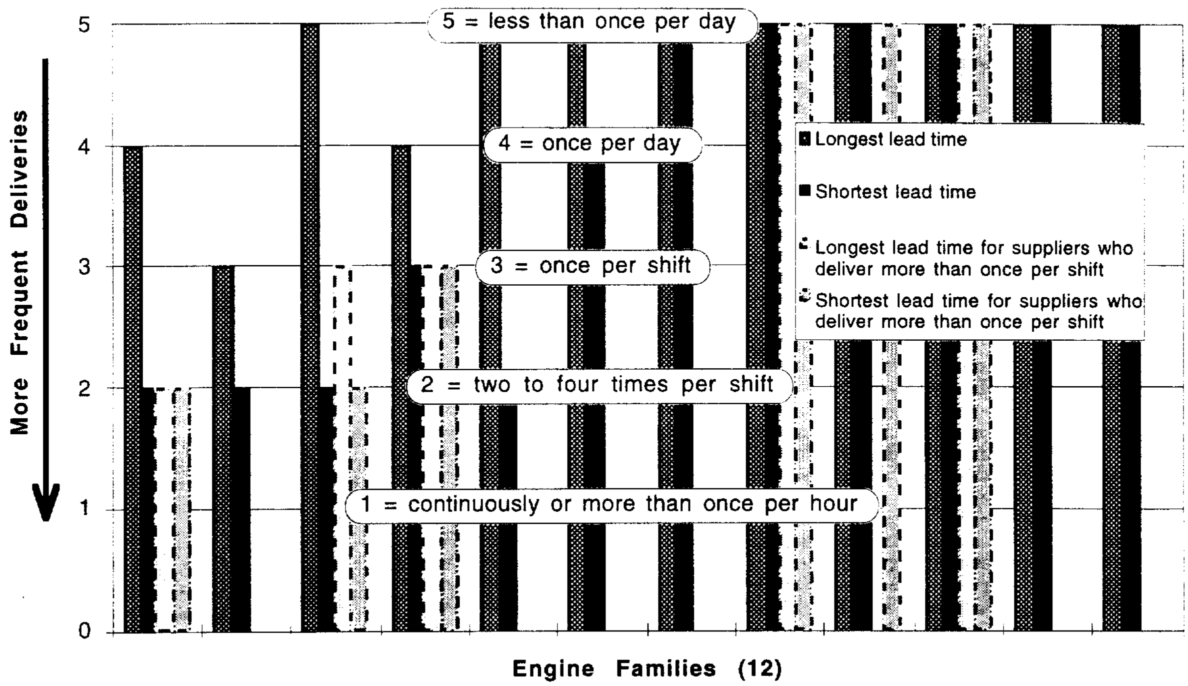


Chart 2.8

Analysis of the data

With suppliers which deliver more than once per shift, deliveries of parts to both the machining and assembly departments of engine plants tend to be more frequent than with the other kind of suppliers. There is nothing surprising about this.

Only in about one third of cases (both for the machining and assembly departments of engine plants) does the *shortest* lead time correspond to delivery of parts which is done once per shift or even more frequently than that.

There is no answer in the category '1', which means that never does the delivery of any part to engine plants from our survey happen continuously or more often than once per hour.

In a vast majority of instances (for both the machining and assembly departments of engine plants), the *longest* lead time is quite high (category '5'), meaning that those deliveries occur at a pace less frequent than once per day.

Frequency and size of delivery of finished engines to the vehicle assembly plants

This first series of questions from Table C.9 deals with the delivery pace of finished engines to the vehicle assembly plants. We have answers corresponding to 21 different engine families, but in regards to the *average* delivery pace, there are 19 answers.

Chart 2.9 (number of answers)

Chart 2.9 indicates the number of engine families which are delivered for each of the five frequency categories proposed (from "less than once per day" to "continuously or more than once per hour" -- cf. above). Actually, the distribution of engine families is plotted for the most frequent, for the average, and for the least frequent delivery paces used by engine plants in our survey.

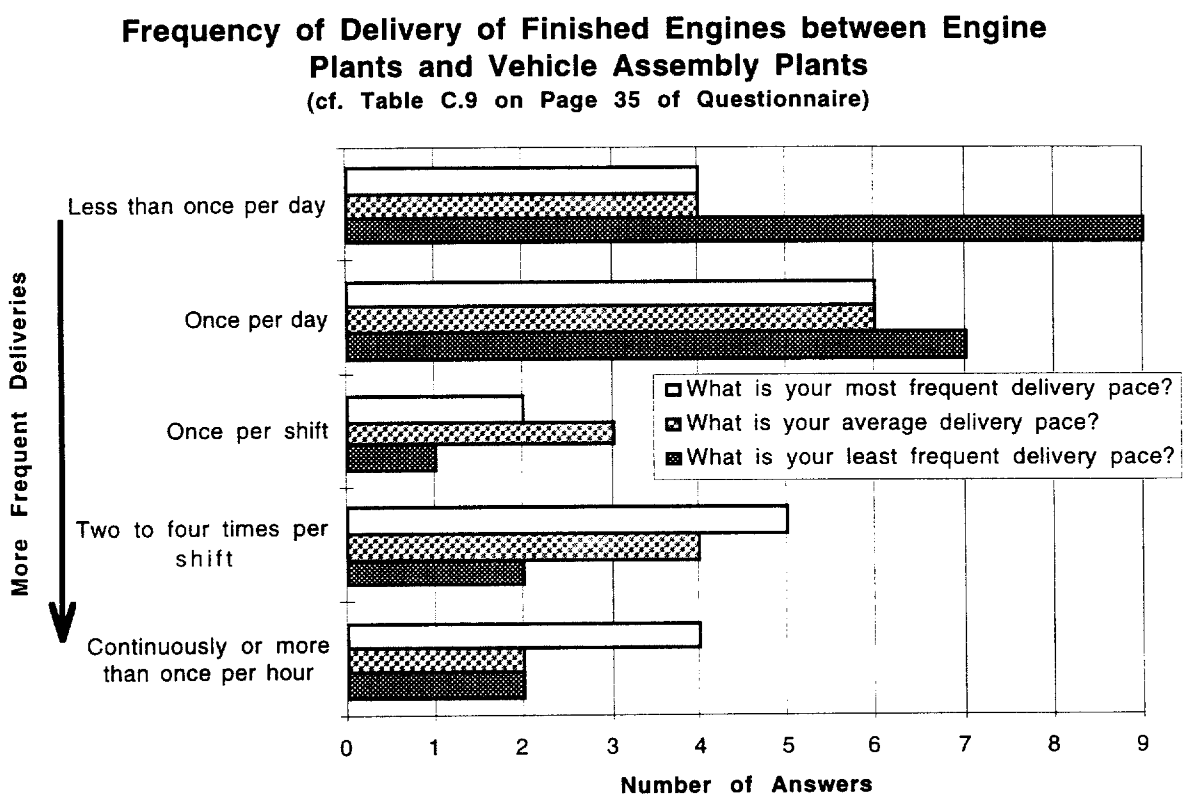


Chart 2.9

Regarding the *average* delivery pace of finished engines, in about 50% of cases (9 out of 19), engines are delivered to the assembly plants once per shift or even more frequently.

However, when one looks at the numbers for the *most frequent* delivery pace utilized, we find that 9 out of 21 engine families are delivered to the assembly plants more frequently than twice per shift (categories '1' and '2').

Some plants deliver finished engines very frequently even when it concerns their *least frequent* delivery pace.

Chart 2.10 and Chart 2.11

These two charts are identical, except for the numbers indicated under the horizontal axis: along with the frequency of delivery of finished engines to vehicle assembly plants, we have decided that it might be interesting to show two parameters:

* average production volume per shift
* average delivery batch size

Horizontal axis: engine families are ranked by increasing average values of category number (a lower category number corresponds to more frequent deliveries).

The left portions of Chart 2.10 and Chart 2.11 illustrate the last point made in the previous paragraph: **engine plants which deliver finished engines very frequently do so in a systematic manner**.

Chart 2.10 shows that the pace of delivery of finished engines to the vehicle assembly plants does *not* depend on how many engines are built per shift.

Frequency of Delivery of Finished Engines between Engine Plants and Vehicle Assembly Plants *(by Engine Family)*

(cf. Table C.9 on Page 35 of Questionnaire)

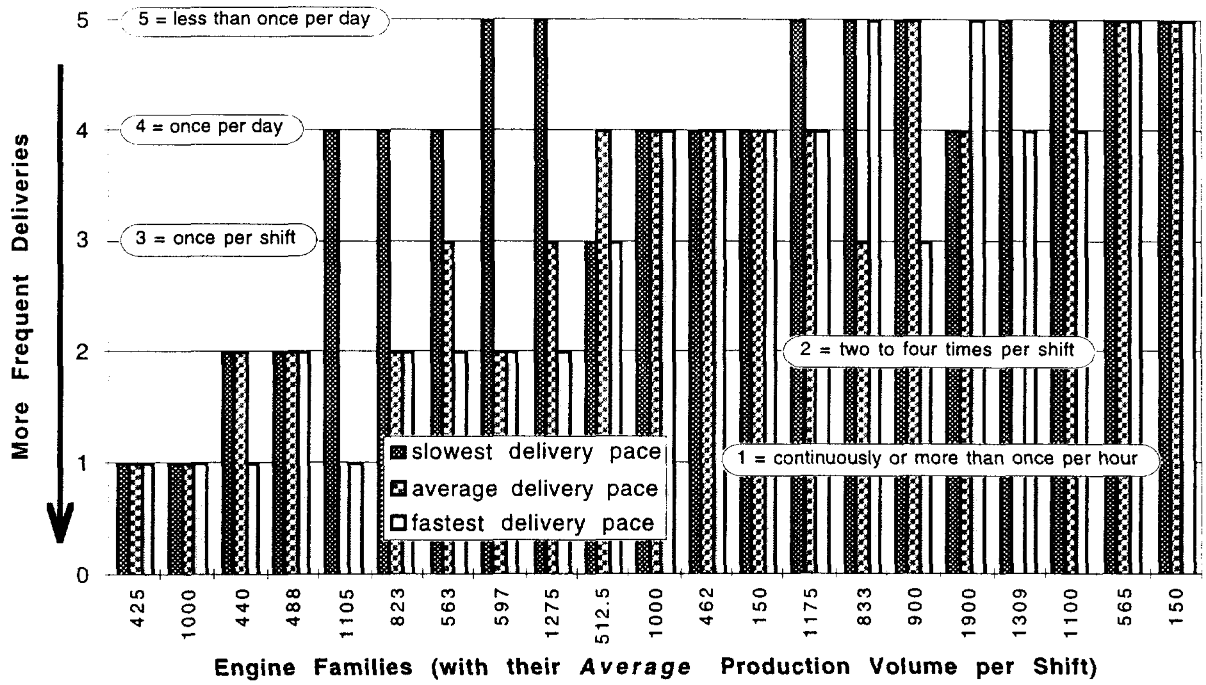


Chart 2.10

In Chart 2.11, we wanted to see if the batch size affects the frequency of delivery of finished engines to vehicle assembly plants. It turns out that those engine families which are systematically delivered very frequently (i.e. somewhere between continuously and twice per shift) are shipped in quite small quantities compared to other instances where the batch size values can be much larger.

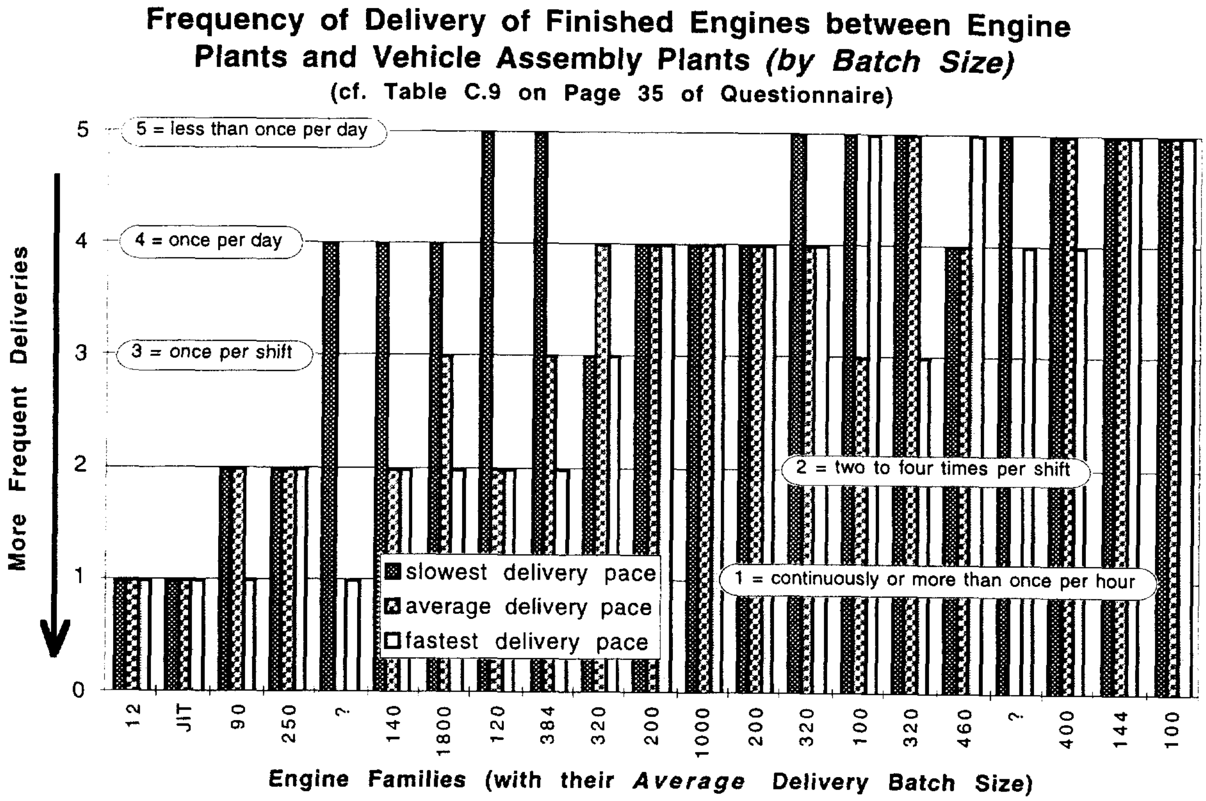


Chart 2.11

Chart 2.12 and Chart 2.13

On Chart 2.12, we plot the minimum, average and maximum number of engines which are sent in one shipment to the vehicle assembly plants.

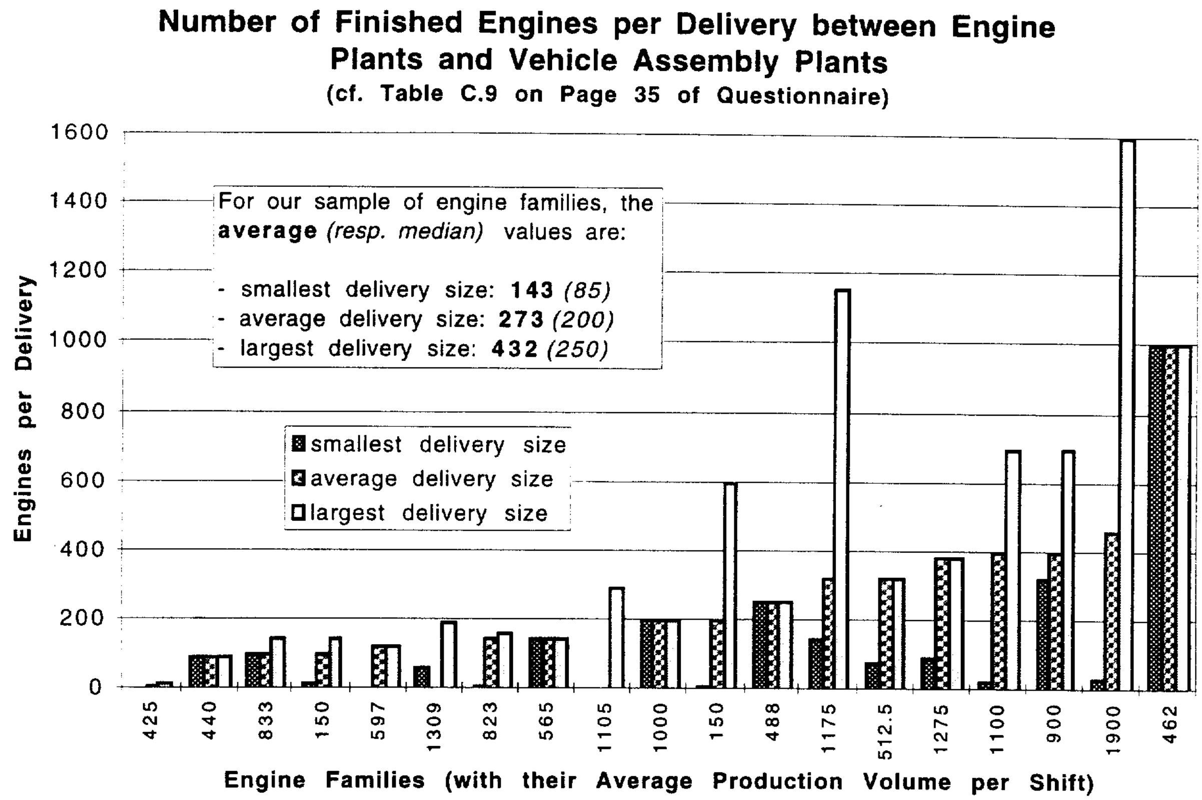


Chart 2.12

Between all the engine families surveyed, the average value of the *average* delivery size of finished engines is 273 units (which is more engines that can fit in one truck; indeed, several engine plants from the survey use rail transport to send their engines to the vehicle assembly plants). This is roughly twice the average delivery size (143 unit) of the *smallest* batches which are shipped out of engine plants.

The bar-graph (cf. Chart 2.12) illustrates the extreme *variety* in shipment and logistical procedures which are in place at the participating engine plants.

In 5 instances (out of 18 answers), finished engines are delivered to their customer vehicle assembly plants in only *one* batch size (there does not seem to be any striking common feature between these 5 engine families). Nevertheless, most engine families studied in our survey end up being shipped to the assembly plants in a variety of *different* batch sizes; these differences can be due to:

* several modes of transportation being used
* usage of the engine family in different vehicles assembled in different locations

* fluctuation in the demand for an engine family

The labels under the horizontal axis of Chart 2.12 indicate the engine families' average production volume per shift, to see if production rate goes in par with delivery size...

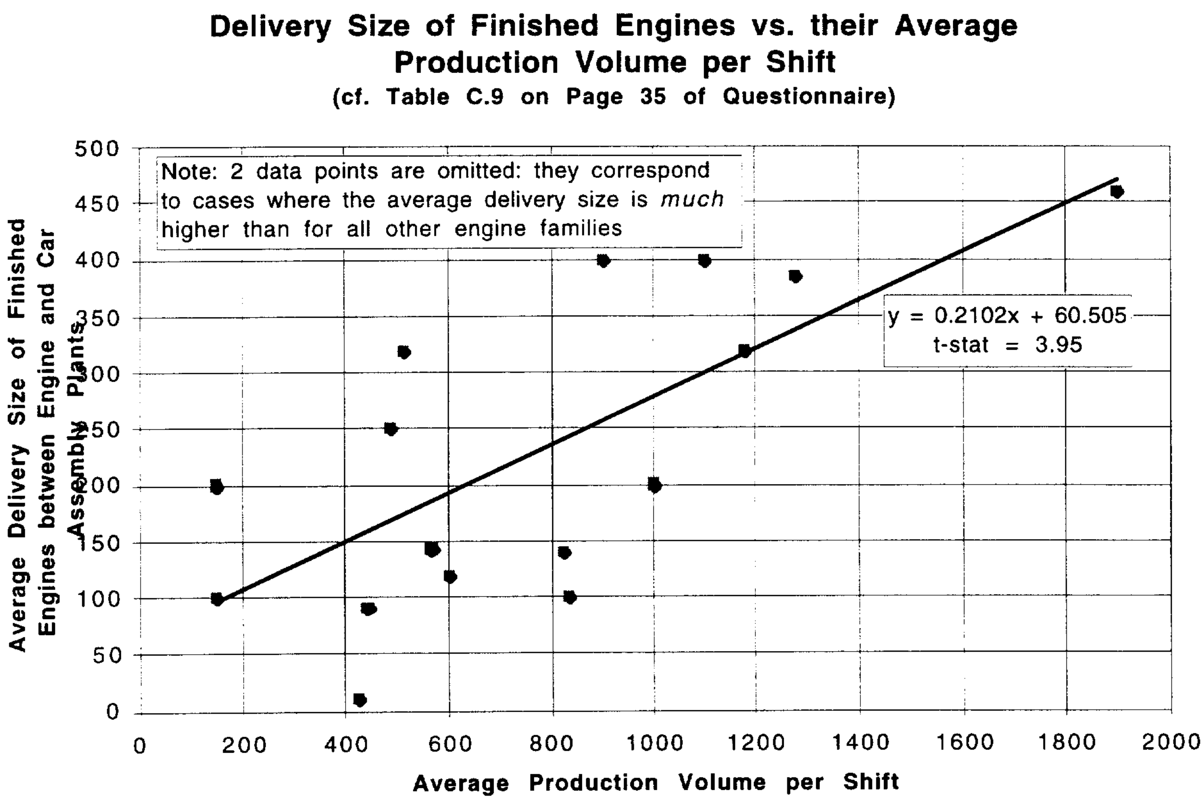


Chart 2.13

... Chart 2.13 provides a partial answer to this question. Omitting two data points out of a total of 18, we ran a regression between the batch size of finished engines and the number of engines produced per shift. The result of this statistical analysis is not too surprising: the **higher** the **number of engines** being **produced** during one shift, the **larger** the *average* **batch size** of the shipments of finished engines to vehicle assembly plants.

Transit time between the engine plant and the vehicle assembly plants

Observations

Because we can observe very large variations in transit time, we find it important to indicate both the average (in **boldface**) values (39 hours) and the median (in *italic*) values (10 hours) of the transit times plotted on Chart 2.14.

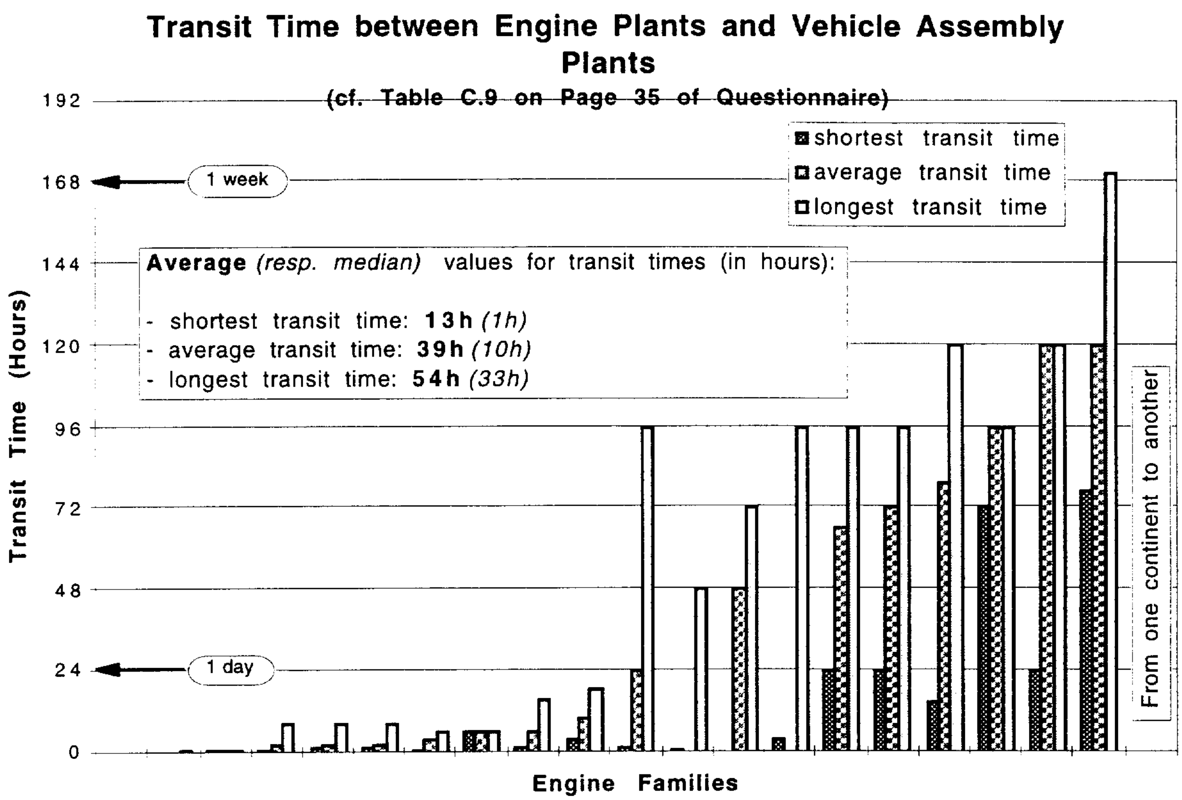


Chart 2.14

For our sample of engine families, the data indicate that **half** of them **have an *average* transit time to their customer vehicle assembly plants of less than half a day**.

About two thirds of the engine families are *sometimes* shipped to vehicle assembly plants located less than 6 hours away from the engine plant.

The shortest transit time between an engine plant and a vehicle assembly plant is sometimes *very* short, because there are instances in our sample where the two facilities are located in the same place (no more than a few buildings apart).

However, there are many engine plants which also deliver engines to vehicle assembly plants located quite far away.

Conclusions

As a conclusion from this chart, we can divide the participating engine plants into **two** roughly equal-sized **groups**:

1. Those engine plants which deal *only* with vehicle assembly plants located very close to them. They are of different sizes, there are some older and some newer facilities among these plants, which are located in Europe, North America, and in Japan. One can notice, though, that the parent companies of the engine plants from this group are either Japanese or from nations of Northern Europe.
2. Others, where the transit time to *some* customer vehicle plants is almost a week.

However, almost *all* engine plants are located less than one day apart from *at least* one vehicle assembly plant with which they deal. This makes a lot of sense -- although the location of a new engine plant can sometimes be influenced by political factors (e.g. tax incentives), in general, companies will try to locate them quite near from a major automobile assembly plant where some of the engines will be delivered.

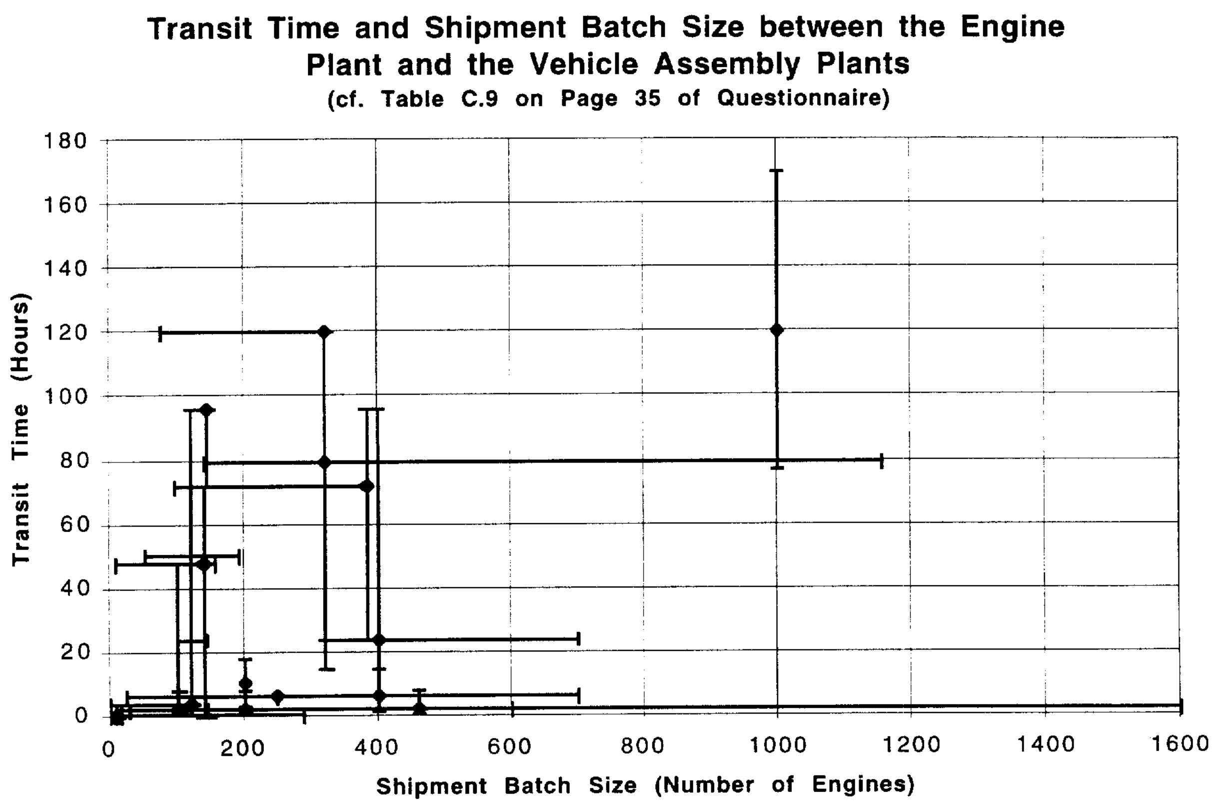


Chart 2.15

Chart 2.15 shows, between each engine plant and its customer vehicle assembly plants, the range of transit time values plotted versus the number of engines delivered by batch (minimum, average and maximum). It is hard to deduct any trend linking the two parameters.

Lead time for the delivery of finished engines to vehicle assembly plants

In this last row of Table C.9 and on the corresponding Chart 2.16, *lead time* represents the time from placement of an order to delivery of the finished engine at the vehicle assembly plant.

Responses are given in a format which has already been described earlier in this section about logistics (for example, a lead time of 3 hours will be in category '2' which means "two to four times per shift"): so, on the vertical axis of Chart 2.16, **the lower the category number, the shorter the lead time** between engine and vehicle assembly plants.

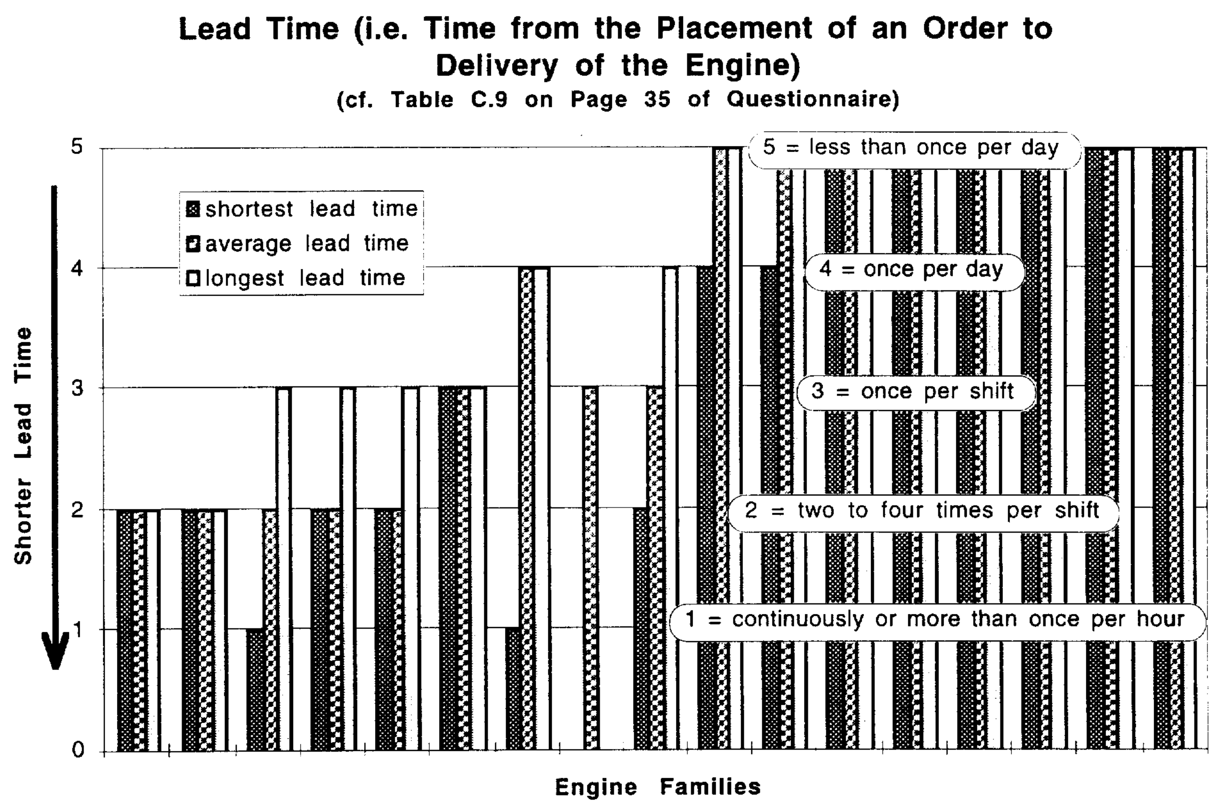


Chart 2.16

The way results are displayed on Chart 2.16 differs from the graph about transit times, but we can still roughly distinguish the same two **groups** of engine plants:

1. Those which consistently have a rather short lead time (less than an 8-hour production shift) between the engine plant and the vehicle plants. About these plants, we can make the same remark as in part 1. of the preceding section.
2. Others, where it can take much more than one day for a vehicle assembly plant to receive a finished engine from the engine plant.

3. Maintenance policies

This section about maintenance policies in automotive engine plants covers questions QC11 to QC19 (cf. pages 35-37 of the questionnaire), as well as the data from Tables C.10 to C.12.

General information

Table 3.1 summarizes the answers from the respondents to our survey.

Maintenance Policies in Engine Plants			
cf. pages 35-37 of the questionnaire			
In most instances, there are answers from 15 different plants			
QC11	Do you have a Total Productive Maintenance (TPM) program in this plant?		
	YES	15	
	NO	0	
QC12	How many years has TPM been in operations?		
	Average = 2.4 years (data from 1995 questionnaire)		
	Ranges from 1 to 5 years		
QC13	% of machines covered by TPM		
	Average = 50%		
	Median = 60%		
	Ranges from 3% to 100% of machines		
QC14	Is the TPM system based on a centralized planning and information system?		
	YES	11	
	NO	4	
QC15	Is the TPM system...		
	... manual?	4	
	... computer-based?	8	
	... both?	3	

Table 3.1

- QC11: *All engine plants* surveyed said that they had a TPM (Total Productive Maintenance) program.

- QC12: However, as of 1995, **TPM** was a **very recent policy** for these companies Indeed, at that time, it had been in use for 1 to 5 years, depending on the engine plant (average = 2.5 years).

- QC13: The fraction of machines covered by TPM ranges from almost none of the equipment to all of it (average = 50%).

- QC14: In a vast majority of cases (11 out of 15), the TPM program is based on a centralized planning and information system.

- QC15: Also, in 1995, almost all plants' TPM systems were computer-based to some extent. However, the 4 which were run without any computer assistance were all based on a centralized planning and information system.

Table 3.2 summarizes the answers from the respondents to our survey.

QC16	What items are kept track of for each machine?			
& Table C.10	Are the data or information displayed at the machine?			
	Item (Number of '*' = number of answers)	Item tracked?	Data displayed?	Item tracked and data displayed?
	Instructions for preventive maintenance	* * * * *	* *	* * * * * * *
	Instructions for common repairs	* * * * *	* *	* * * *
	Downtime record	* * * * * * *	* *	* * *
	Lessons learned	* * * * *	*	* * * * * * *
	List of future repairs needed	* * * * * * * * *	*	* * *
	Training history of repair people	* * * * * * * * * *	*	* * *
QC17	How many times is preventive maintenance done *per week* ?			
	Average = 1.5 times per week			
	Ranges from 0.5 to 15 times per week			
	Number of plants which said once a week: 6			
QC18	How many hours of productive maintenance are done each week?			
	Average = 2.1 hours per week (8 answers)			
	Ranges from 1 to 4 hours per week			
	Other kinds of answers:			
	* Employee(?) hours per week spent: 170, 300, 300, 1000, 4400			
	* 1 hour per machine			
	* 15 minutes per day per worker			
QC19	Items which are attended to during preventive maintenance			
		YES	NO	
	Lubrication	15	0	
	Tightening things	12	3	
	General cleaning	14	1	
	Cleaning out drains and filters	12	2	
	Spec checklist of elec, mech, and hydr iten	12	3	
	Calibration	13	2	

Table 3.2

- QC16: Which items do people keep track of? Do they display the information? The proposed list of items is:

  * instructions for preventive maintenance,
  * instructions for common repairs,
  * downtime record,
  * lessons learned,
  * list of future repairs needed,
  * training history of repair people.

The answers to this question and the results from Table C.10 are given on Table 3.2. There are 15 engine plants for which we have information about maintenance policy. It turns out that **for a vast majority of the plants** (between 11 and 14), **the six items listed above are either tracked or the information is displayed, or both**.

Regarding one particular item, we were very interested to check if there was any correlation with some other manufacturing data. Precisely, in those plants where the *downtime record* of machines is displayed, are downtime values actually lower than in the plants where they are not displayed? By performing the Student t-test, we can conclude that there is no such correlation: no matter which downtime data one looks at (should it be unscheduled, scheduled, or total downtime), **whether it is displayed along the machines or not doesn't "differentiate" plants with low downtime from plants with high downtime values**. This does not mean that displaying downtime records will not help lower downtime, but there is no evidence that this procedure (alone) does!

- QC17: The **frequency** at which **maintenance** is done in engine plants dramatically **varies** from one facility to another. Indeed, it ranges between:

  * once every two weeks, to...
  * 15 times per week.

In 6 plants is maintenance done only once per week. This compares with an "average maintenance frequency" of *one and a half times per week* (because the average duration between maintenance events is 0.67 week).

- QC18: To this question about **time spent on maintenance**, the respondents answered in different ways. However, out of 8 engine plants which answered in terms of "hours per week", the average value is just above 2 hours (ranges from 1 to 4). Some other kinds of answers were given, as shown on Table 3.2 (e.g. "15 minutes per day per worker", or "1 hour per machine", or the number of employee-hours spent per week).

- QC19: Some key **maintenance items** were mentioned in the questionnaire, in order for us to know if engine plants attend to them as part of their preventive maintenance policies. As shown in Table 3.2, for all of these items, almost all plants *did* care about them.

Preventive maintenance, breakdown and repair policies

Tables C.11 and C.12 examine the extent to which suppliers of equipment and the automobile company itself are involved in the engine plants'

* preventive maintenance policies,
* breakdown and repair policies.

Maintenance Policies in Engine Plants

cf. page 36 of the questionnaire

Table C.11 How frequent is each of the following situations for your **preventive maintenance** policies? ('1' = most frequent, '2' = next most frequent)

Preventive Maintenance Policies

Situation	Most frequent... 1	2	3	4	5	6	... Least frequent 7
The equipment supplier maintains machines		*	***	**	***		**
An outside contractor maintains them		***	*	****	*	***	*
Another division of our company or affiliate company maintains them		*	*		**	*	***
The supplier trains our special maintenance crew which then does the maintenance	*****	***	***	**	**		
The supplier trains our production workers who then do the maintenance		***	*	****	*	***	
Our company trains our own maintenance crew	*********	****	**				
Our company trains the production workers who do the maintenance	***	*****	**	**	*		
	Note: not all respondents gave answers between 1 and 7						

Table C.12 How frequent is each of the following situations for your **breakdown and repair** policies? ('1' = most frequent, '2' = next most frequent)

Breakdown and Repair Policies

Situation	Most frequent... 1	2	3	4	5	6	... Least frequent 7
The equipment supplier maintains machines			***	**	***	**	**
An outside contractor maintains them		*	*	**	***	***	**
Another division of our company or affiliate company maintains them		**			**	*	***
The supplier trains our special maintenance crew which then does the maintenance	***	********	**	*	*		
The supplier trains our production workers who then do the maintenance	*	**	*	****	*	**	
Our company trains our own maintenance crew	**********	**	*	**			
Our company trains the production workers who do the maintenance	**	***	****	*	**		
	Note: not all respondents gave answers between 1 and 7						

Table 3.3

For *both* of these policies, the two most frequent situations are that the engine plants' maintenance crews are trained by (i) the company (most often) and (ii) by the equipment supplier; there is no incompatibility that both situations happen, because we can easily imagine that an engine plant with its own maintenance crew also wants that these people be trained by the suppliers of some of the machines which might be newer or more complex.

Sometimes, machines in engine plants are maintained by either the equipment supplier or by an outside contractor.

We should note that for the *preventive* maintenance policies, it is very common practice for engine plants to have some of the production workers trained *in addition to* the dedicated maintenance crew members.

Overall, the answers to questions in both tables look very much alike: as a group, the plants surveyed have quite similar approaches towards preventive maintenance policies and towards breakdown and repair policies (see the data displayed on Table 3.3).

Types of breakdowns (% distribution)

For each department of the engine plants (machining lines, assembly and test lines), we asked what kind of breakdowns were most frequent. The answers are given as *percentages* by type of breakdown. Keep in mind that the actual number of breakdown occurrences might vary a lot from plant to plant.

The five different categories of breakdowns are:
* mechanical,
* electrical,
* hydraulic,
* tool breakage,
* "other" types of breakdowns.

By looking at *average* values (cf. Chart 3.1), one can conclude a few things:

1. **Mechanical failures account for more than 40% of breakdowns in all of the departments** within the engine plants surveyed.

2. **Electrical failures are the second most occurring types of breakdowns overall**. It is in the assembly and test departments that their occurrence (as a % of all breakdowns) is highest, probably due to the kind of equipment present in these departments.

3. Consequently, engine plant breakdowns due to hydraulic, tool breakage, or other kinds of problems, represent about 25% or less of the instances of breakdowns in the machining lines and in the assembly and test lines. Not surprisingly, one can note that tool breakage breakdowns are extremely infrequent (less than 1% of instances) in the assembly and test departments, i.e. in the *non*-machining departments of engine plants.

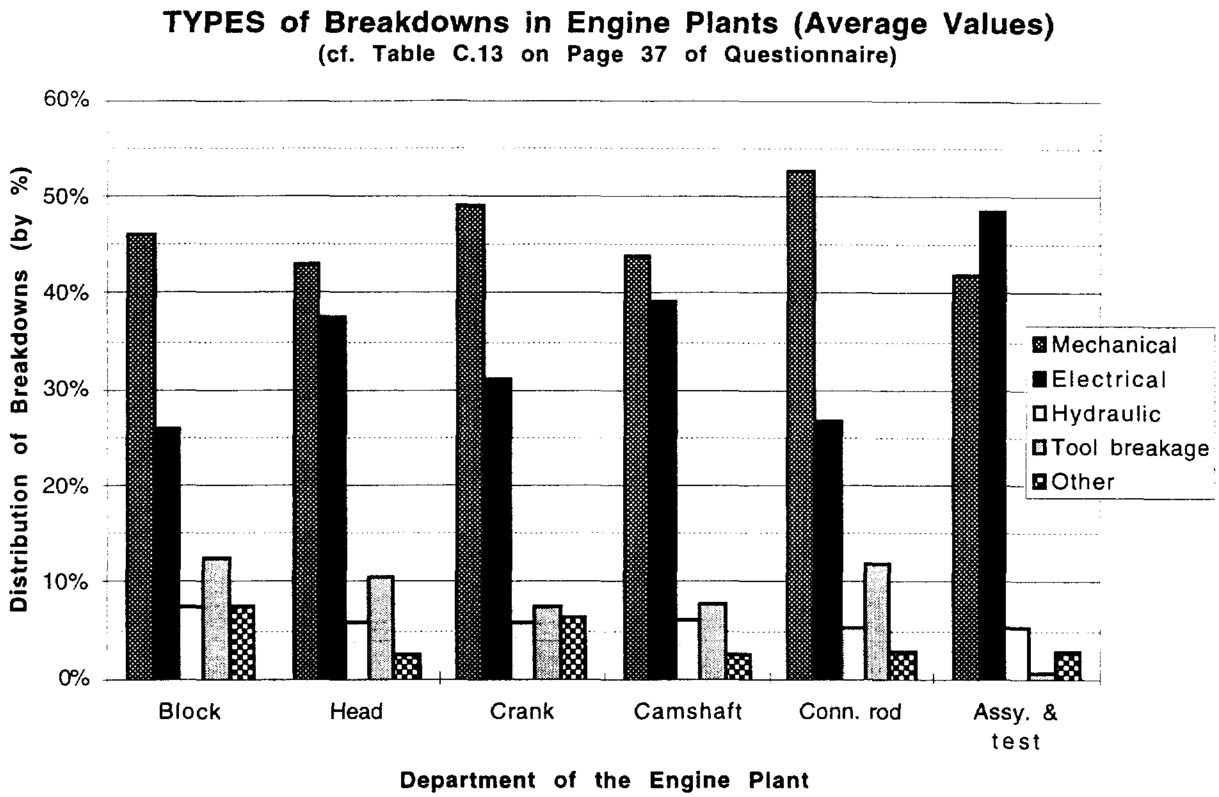


Chart 3.1

However, beyond these average values which clearly indicate to us that an overwhelming fraction of breakdowns are due to mechanical or electrical problems, it is important to note that the **relative distribution of breakdowns varies greatly from plant to plant**. This point is illustrated by Chart 3.2. We wondered if the types of breakdowns could be correlated with the age of the engine plant. Most of the time, the regression between the age of plants and the % values of a type of breakdown does not show any significant result. However, *hydraulic* breakdowns clearly constitute the category for which the correlation with the age of engine plants is strongest, and this holds true for *all* of the machining departments, *and* for the assembly and test departments: namely, **the older the engine plant, the higher the fraction of breakdowns which are due to *hydraulic* problems**. For mechanical breakdowns, it is the contrary: older engine plants tend to have relatively fewer breakdowns due to mechanical problems, but the correlation is not very strong at all.

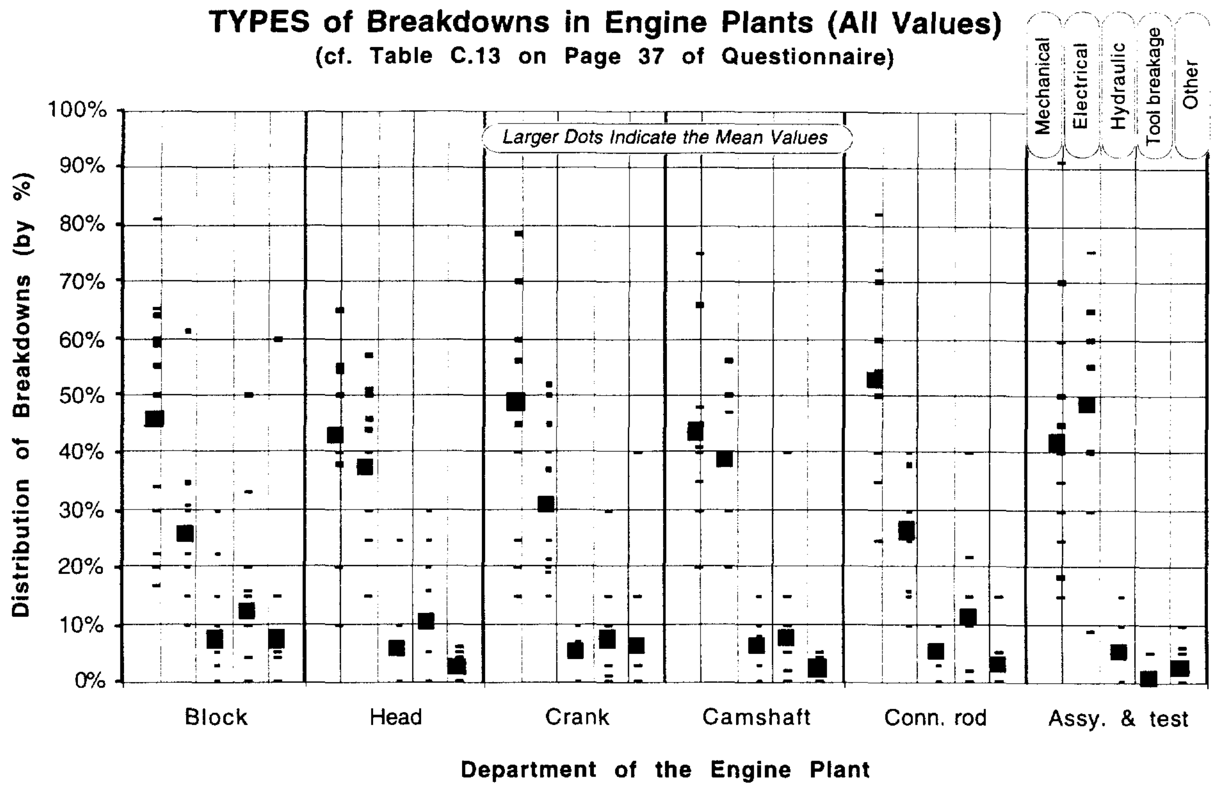
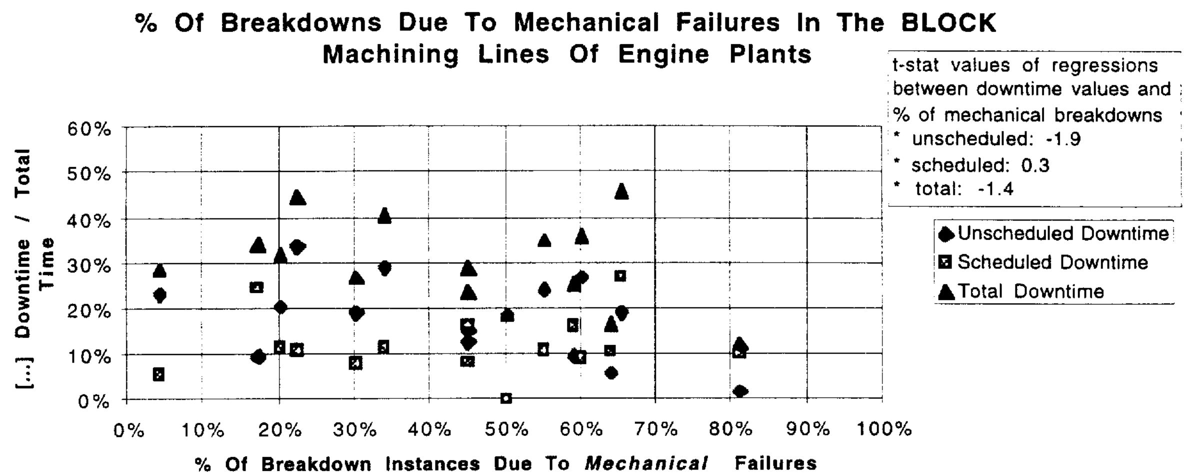
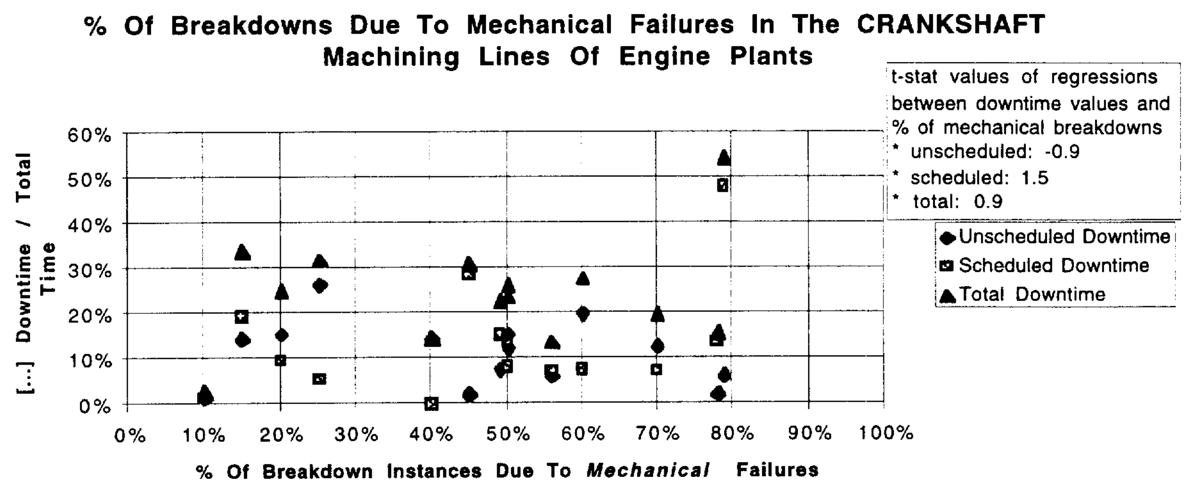


Chart 3.2

We then considered those breakdowns which overall occur most frequently, i.e. those due to mechanical and electrical problems. We tried to see if there was, throughout the machining lines of cylinder blocks, crankshafts and cylinder heads, any kind of relation between the share of breakdowns due to mechanical and electrical failures, and the downtime values for these production lines. As shown by the statistical analysis on the graphs of Chart 3.3 and Chart 3.4, there is **no** consistent or strong **correlation between** any kind of **downtime** value (be it unscheduled, scheduled, or total) and the percentage of **breakdowns** due to mechanical failures (Chart 3.3) or electrical failures (Chart 3.4).


% Of Breakdowns Due To Mechanical Failures In The BLOCK Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of mechanical breakdowns
* unscheduled: -1.9
* scheduled: 0.3
* total: -1.4
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Of Breakdown Instances Due To Mechanical Failures


% Of Breakdowns Due To Mechanical Failures In The CRANKSHAFT Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of mechanical breakdowns
* unscheduled: -0.9
* scheduled: 1.5
* total: 0.9
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Of Breakdown Instances Due To Mechanical Failures

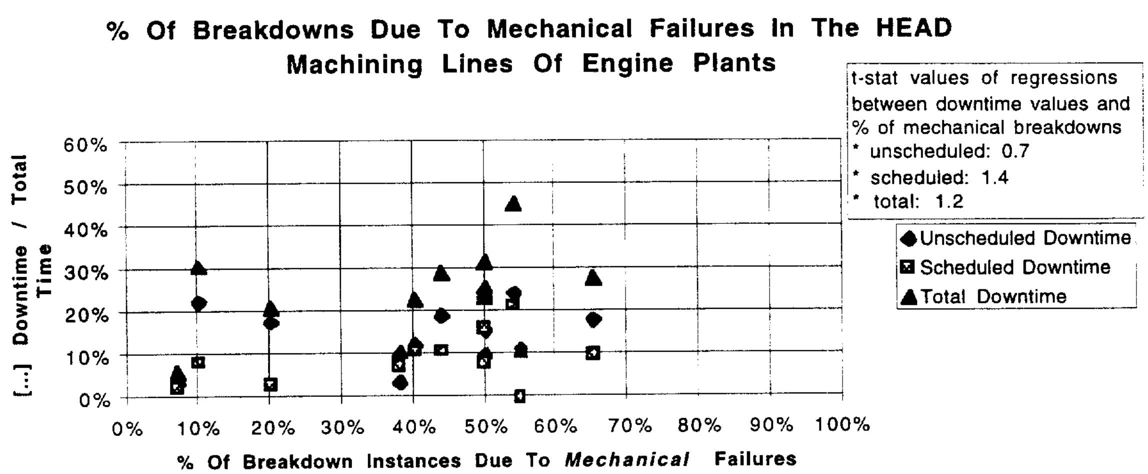
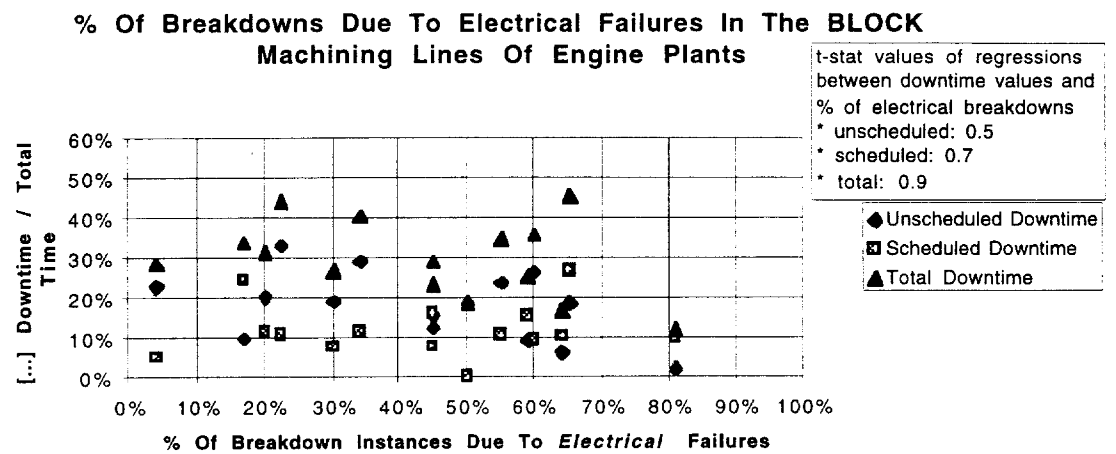
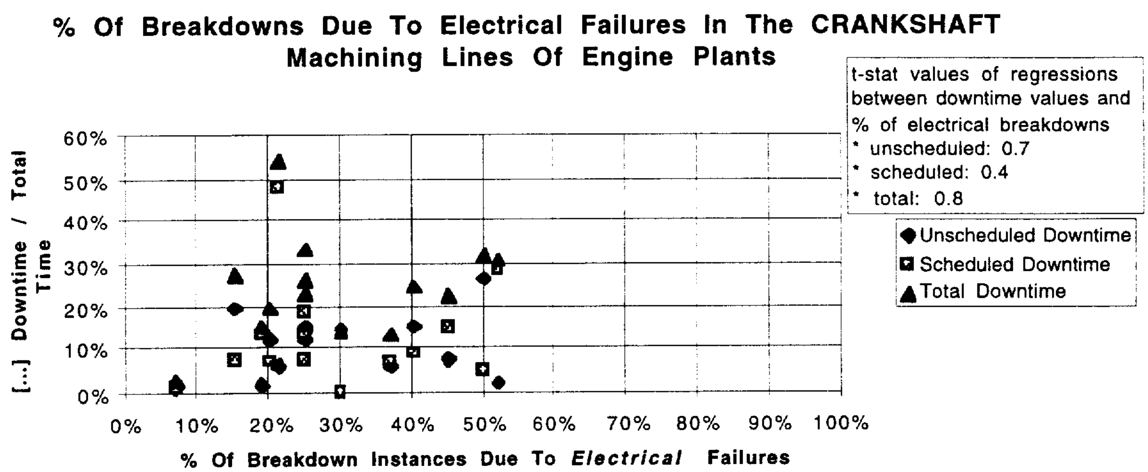

% Of Breakdowns Due To Mechanical Failures In The HEAD Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of mechanical breakdowns
* unscheduled: 0.7
* scheduled: 1.4
* total: 1.2
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Of Breakdown Instances Due To Mechanical Failures

Chart 3.3


% Of Breakdowns Due To Electrical Failures In The BLOCK Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of electrical breakdowns
* unscheduled: 0.5
* scheduled: 0.7
* total: 0.9
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
% Of Breakdown Instances Due To Electrical Failures


% Of Breakdowns Due To Electrical Failures In The CRANKSHAFT Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of electrical breakdowns
* unscheduled: 0.7
* scheduled: 0.4
* total: 0.8
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
% Of Breakdown Instances Due To Electrical Failures

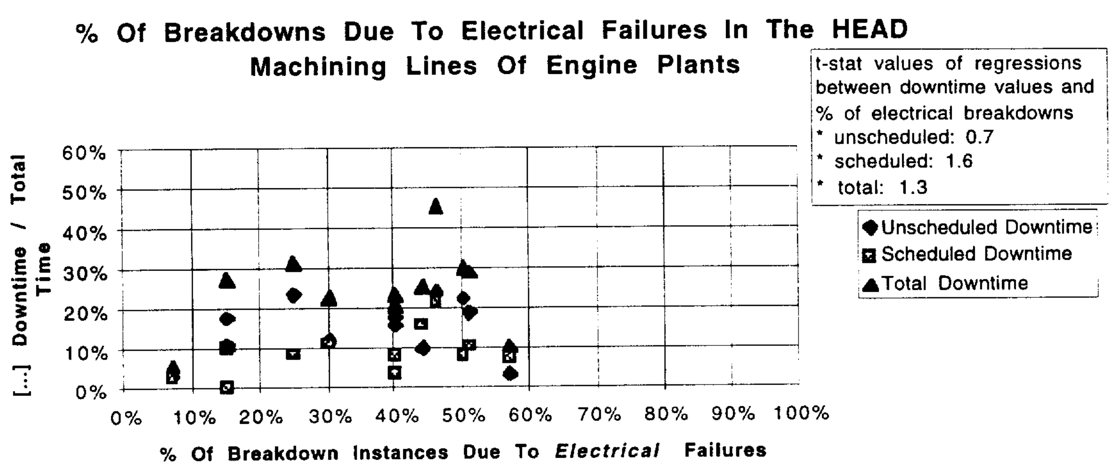

% Of Breakdowns Due To Electrical Failures In The HEAD Machining Lines Of Engine Plants
t-stat values of regressions between downtime values and % of electrical breakdowns
* unscheduled: 0.7
* scheduled: 1.6
* total: 1.3
Unscheduled Downtime
Scheduled Downtime
Total Downtime
[...] Downtime / Total Time
60%
50%
40%
30%
20%
10%
0%
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
% Of Breakdown Instances Due To Electrical Failures

Chart 3.4

4. Production technologies

Results from the analysis of Table C.17 (sequence of events in engine and plant design) and Table C.18 (desirable properties of machines) from the questionnaire have already been shared with the sponsors of this study in the end of 1996.

Flexibility and equipment procurement are topics of strong interest in the engine R&D and engine manufacturing "communities". When reading articles about "modular" engines, or when visiting engine plants, one can easily catch a glimpse of some pros and cons associated with flexible equipment. For example, "flexible" machines are often very expensive, but flexibility can help make better use of existing production capacity; moreover, flexible machines are sometimes brought in to reduce the cycle time of some complex machining operations. Also, on the technical side, a 90-degree vee angle for a V-6 engine is not the optimal configuration, but it enables the blocks of V-6 and V-8 engines to be machined on the same line, thus enabling the engine plant to be more flexible in its response to relative ups and downs of demand for V-6 and V-8 engines.

Flexibility

Following are some data covering approximately twenty engine families, on the topic of plant flexibility currently in place throughout the automotive industry.

- QC20 asked about the time frame for major **upcoming changes** concerning the main machining and assembly lines in engine plants. On Chart 4.1, we plot the year when this next major change will take place; one can note that around the 1996-1997 period, we are in the middle of great "overhaul" activity for many engine plants. For your information, we also show the dates when each engine plant opened and when it was last refurbished. It is interesting to note that plants which are not that old (e.g. which have operated since the mid-eighties) are facing major changes quite soon. Maybe that some of this is due to an increasing pressure nowadays to upgrade engines (and therefore engine plants) more frequently than previously, as the life-span of engine families gets shorter. Obviously, answers to a question like this one are subject to the respondents' appreciation of the degree of "change" affecting the engine plants.

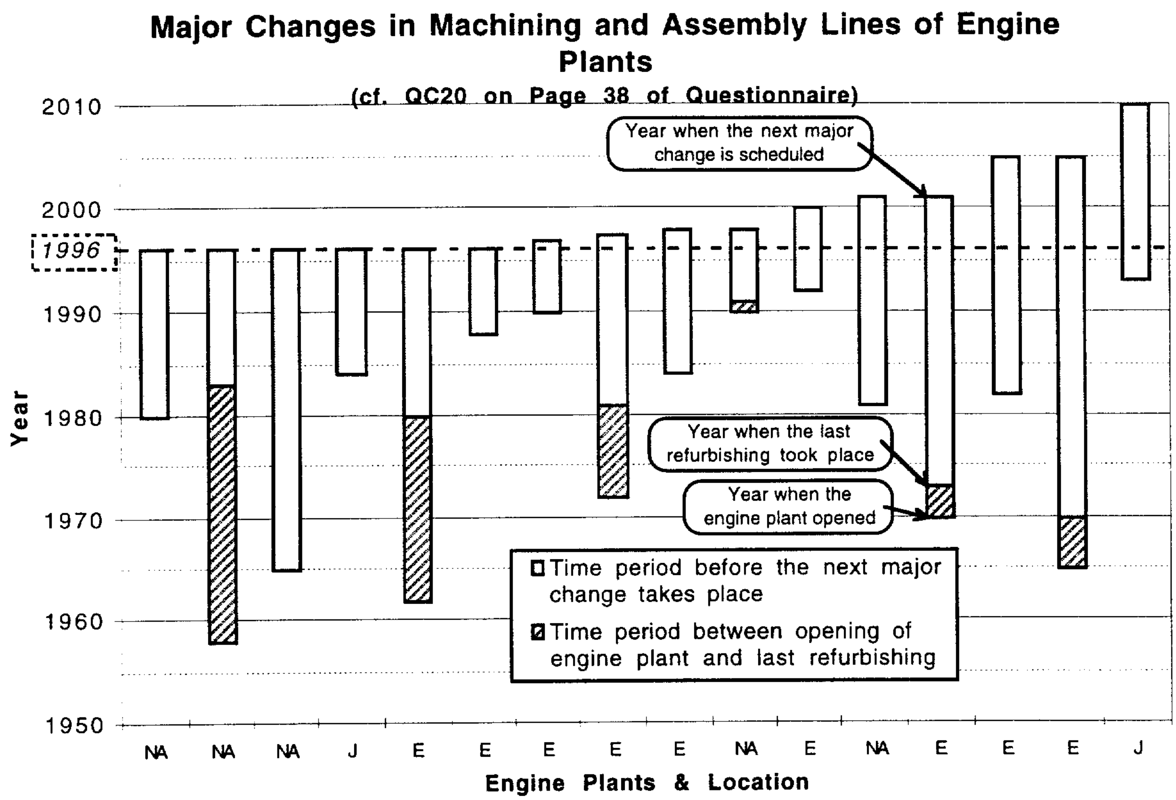


Chart 4.1

- QC21: the **percentage of machines which can be reused** in an installation for a new engine variant is **over 50%** except for one case (cf. Chart 4.2). Many engine plants are much more flexible than that, though, because half of them indicate that more than 90% of the machines can be reused. Again, with such data, one has to be aware that respondents might not all have in mind the same kind of "variant change" when they answer to this question…

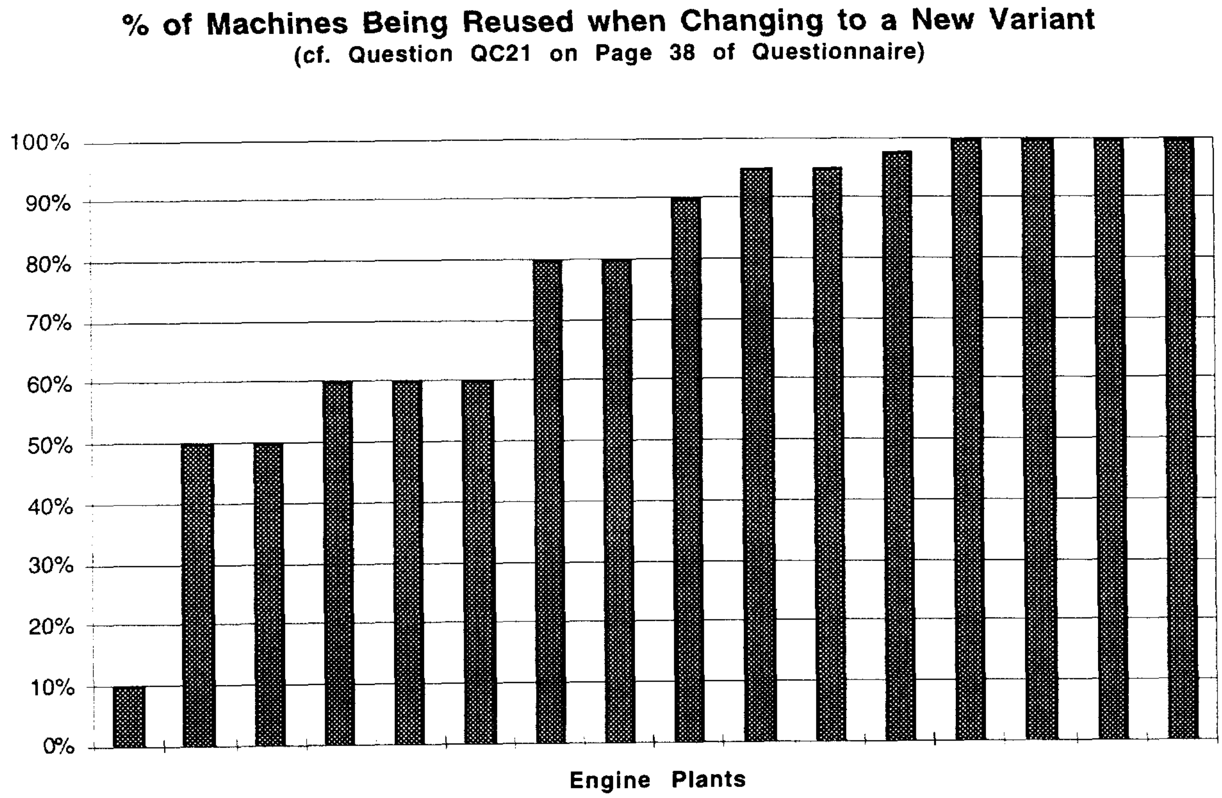


Chart 4.2

- QC22: how long is an engine plant machining or assembly line stopped due to the installation of a "**minor upgrade**"? Like for so many sections of this questionnaire about engine manufacturing, the **answers** from the plants surveyed **vary a lot**. In a majority of cases, it takes between one and five days... but some plants require three to four weeks, while two others need much less than 24 hours (cf. Chart 4.3)!

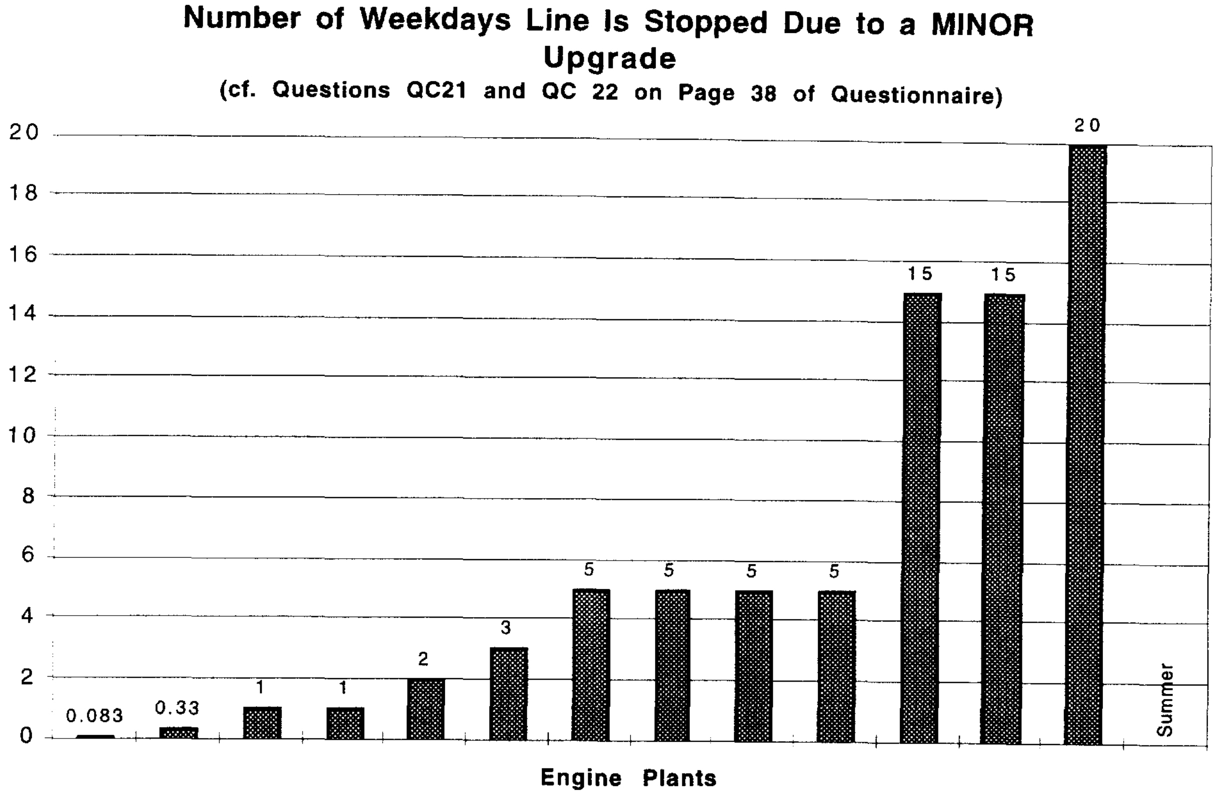


Chart 4.3

- QC23 lists a series of tasks which we want to know if engine plants are capable of performing. Answers regarding these kinds of flexibility are shown on Chart 4.4 which is quite self-explanatory. We can notice that, as a group, engine plants in 1995 were capable of **more flexibility in the assembly departments than in the machining departments**. For only three cases is the engine plant equipment such that several engine *families* can be machined on one line (this select group includes the two Japanese facilities from our survey). These three engine plants are not among the older ones, as they date from after the mid-1980's. In those three facilities, several variants can be assembled as well.

Types of Flexibility Engine Plants Are Capable of in 1995
(cf. Question QC23 on Page 38 of Questionnaire)

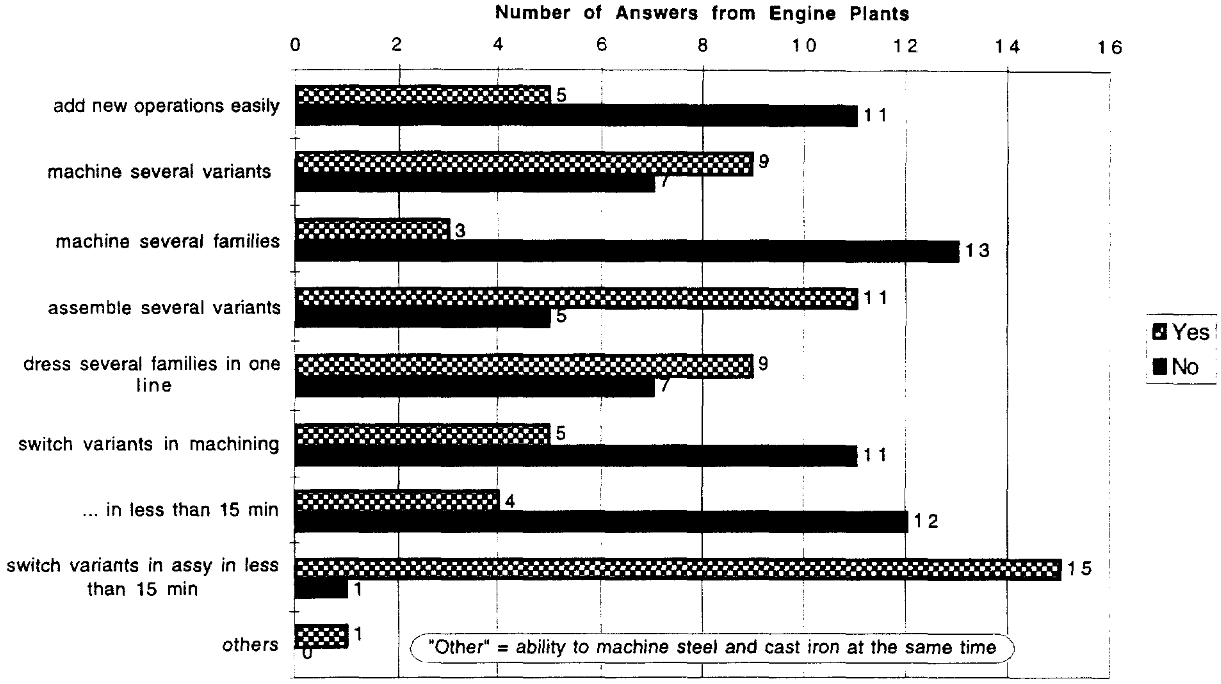


Chart 4.4

In Table 4.1, we summarize answers to questions QC24 to QC28

Flexibility (cf. Questionnaire on Pages 38 and 39)				
QC24: All but one of the 16 respondents say that they can *estimate* the cost of adding a new engine variant				
QC25: Most likely effects which adding a new variant will have on the operations of the plant				
	Plant # 1	Plant # 2	Plant # 3	Plant # 4
most important effect	integrated lines retooling	new machines	capacity	new machines
next...	matl flow management	more floorspace	logistics	more floor space
next...	loss of capacity for setup time	more manpower	people	more manpower
next...	info system modification	less capacity	quality	less capacity
next...	components suppliers		safety	
	Plant # 8	Plant # 9	Plant # 10	Plant # 11
most important effect	less overall capacity	compatibility of process	capital investment	new tools
next...	quality lost	means	ratio control-prod system control	upgrade of machines
next...	new machines	investment	impact on overall capaciyty	change parts of equip
next...	more people necessary	logistics		buy new machines
next...	more storage space	times of execution		
QC26: Sequencing pattern the assembly line is **capable** of:				
	* No set pattern:	9 cases (/16)		
	** 1-2-1-2-1-2-:	4 cases (/16)		
	*** Batches like 1-1-1-2-2-2-:	9 cases (/16)		
QC27: Sequencing pattern usually **used**:				
	* No set pattern:	6 cases (/16)		
	** 1-2-1-2-1-2-:	1 case (/16)		
	*** Batches like 1-1-1-2-2-2-:	1 0 cases (/16)		
... Batch size: 6, 6, 24, (40-70), 50, 64, (36, 72 or 144), 300, 400, a few hundreds				
QC28: Flexibility improvements for future				
	Plant a	Plant b	Plant c	Plant d
	same approach	added CNC cells	modular manufacturing in all	added CNC m/c cells
			machining and assembly operations	
	Plant g	Plant h	Plant i	Plant j
	eliminate or dominate changes	no further plans	new displacement (stroke change),	Diesel engine manufacture in this plant,
			4 valves per cyl.,	reduce variants within company
			alu. cyl. block machining	

Table 4.1 (i)

QC25 (cont'd)		
Plant # 5	Plant # 6	Plant # 7
requiring new machines	rebuilding of machines	new machines, stations
more storage space	changed work distribution	space
less overall capacity	changed logistic cycle	technology
	more direct people	integration into existing prod flow
	new machines	storage
Plant # 12	Plant # 13	Plant # 14
cost increase	require new machine or adapt existing ones	investment
reduced overall capacity / reduced productivity	new tools	labor
investments required for new machines, tooling, test equipment	new control instruments	ground
more personnel may be trained	schedule for test and starting	logistic
effect on quality	storage areas	capacity
more logistics personnel required		
more complex control systems		
more storage area required		
more training required for personnel		
more work involved for spare parts		

QC28 (cont'd)		
Plant e	Plant f	
reduce size of batch	maintenance, operator flexibility impovement	
Plant k		
acquire new flexible machines		

Table 4.1 (ii)

- QC24: 15 out of 16 respondents claim that they can *estimate* the cost of adding a new engine variant. This is quite surprising: indeed, during our visits to automotive engine plants, management people always indicated that, as their facilities had had to manufacture more and more engine variants, they did not know what overall impact it had on the cost structure and on the productivity of their engine plant.

- QC25: we asked to the engine plants what kind of **impact** there could be, **due to the addition of a new variant**. A variety of answers were given: they are summarized in Table 4.1. We can point out some of the effects which were mentioned most frequently:

 * logistical concerns (especially inside the engine plant itself),

 * capacity problems,

* impact on machines,
* quality and labor issues (to a lesser extent).

- QC26 and QC27 refer to the assembly line of engine plants, looking at the sequencing patterns which *can* be used and those which *are* actually being used. The most preferred and used **sequencing pattern is 1-1-1-2-2-2**. In such instances, batch sizes vary enormously, from 6 to hundreds of engines. Table 4.1 describes the answers given by engine plants.

Equipment design and acquisition

In this document, the only data presented is the one from Tables C.14, C.15 and C.19. Some information about the equipment acquisition process (cf. Table C.16), the sequence of events in engine and plant design (cf. Table C.17), and desirable properties of machines (cf. Table C.18) had already been shared with IMVP sponsors (cf. package of slides sent after the meeting in Paris in October of 1996).

Tables C.14 and C.15

Interestingly, for all but one engine plant, **the current and future processes for designing and acquiring equipment are identical**. As shown on Table 4.2, for 11 out of the 15 respondents, the way things works is as follows:

1. **In most circumstances, the company *specifies* the requirements for the equipment, but other companies design, build and install it**.
2. Sometimes, the company buys the equipment from other companies and installs it.
3. Even less frequently, the company designs and builds the equipment and installs it.

Results from the analysis of results from Tables TC14 and TC15 of the questionnaire (p. 39)				
ACTUAL (TC14) and DESIRED (TC 15) **equipment design and acquisition process** are IDENTICAL in all but one case				
Situations:	Type of answer series:			
* our company specifies the requirements for the equipment, but other companies design, build and install it	1	1	2	
** our company buys the equipment from other companies and installs it	2		1	
*** our company designs and builds the equipment and installs it	3		3	
	Number of instances			
	11	**2**	**2**	
Note about Answers:			Note: in one of	
"1" = most frequent situation			these two instances,	
"2" = next most frequent situation			*desired* process is 1/2/3	
"3" = next most frequent situation				

Table 4.2

Note that for two engine plants, the *only* process in place is that the company *specifies* the requirements for the equipment, but other companies design, build and install it.

Table C.19

In this table, engine plants tell us in detail about who takes the leading role regarding the **acquisition strategy for their *existing* machining, assembly, and test lines**.

A) Machining

On Chart 4.5, when we indicate the average, minimum, and maximum number of answers, it is those values calculated between the different *machining* lines from our sample. One can notice that there is almost no difference between the various machining lines: in other words, for *any* machining line, the acquisition strategy is identical; by acquisition strategy, we comprise these six activities: definition of requirements, process planning, design, building, system integration and installation of equipment. When one looks at the answers plant by plant, one also observes the same pattern: in every engine plant, **the acquisition strategy is basically similar across all machining lines**.

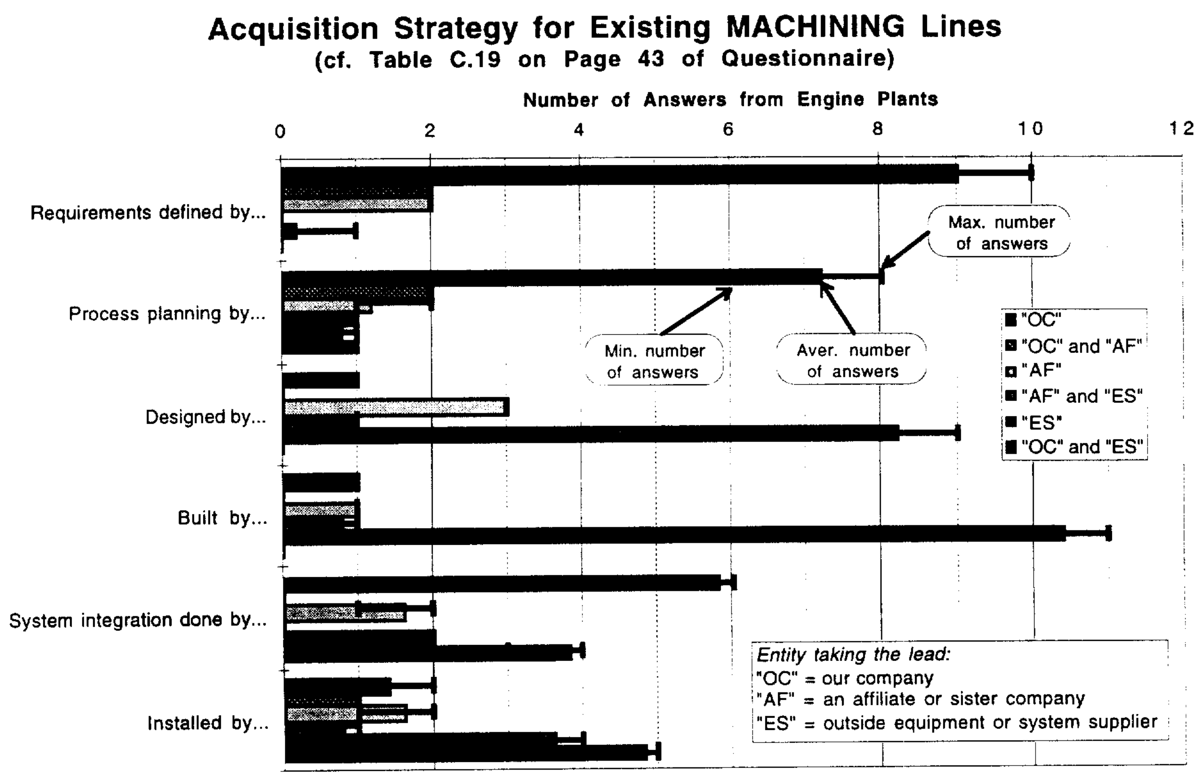


Chart 4.5

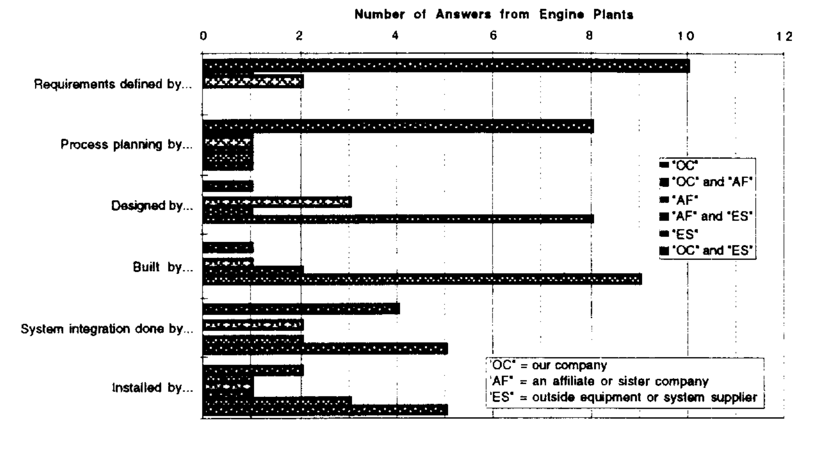
The most common practice for the equipment acquisition strategy of existing machining lines is:

- In a vast majority of cases, the automobile company takes the lead for the definition of the requirements; sometimes, it is helped in that with an affiliate or sister company.
- Process planning is another area where the company and possibly an affiliate or sister company have a strong saying.
- On the contrary, management of the **design and** of the **building of machining line equipment is done by outside equipment or system suppliers in most instances**. However, there are a few engine plants for which a department from the company takes the lead in the design and building of machines; although we do not have answers from many Japanese firms, *their* data suggest that in their case, it is frequent that the company takes the lead in designing the line and/or in actually building the machines. A few European automobile firms also indicate that an affiliate company can be in charge of the design and/or the building of machining lines. When analyzing the results from Table C.16, we had already learned that a small group of companies have a dedicated engineering department or an affiliate company which can build machines for their engine plants.
- Answers from the engine plants indicate that systems integration and the installation of equipment are areas where, in some cases, it is the company which is in charge, while in other cases, some outside company takes care of it.

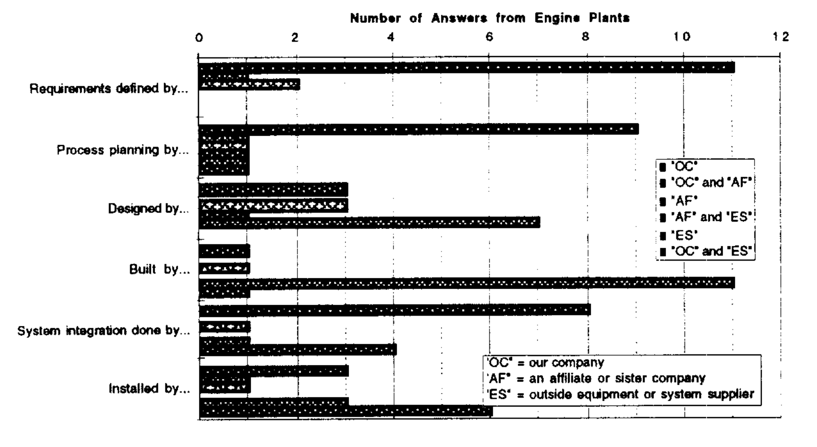
B) Assembly and test lines

For the *assembly and test lines*, the overall results are actually not very different from how the acquisition strategy is conducted for existing machining lines. This is why the graphs from Chart 4.6, Chart 4.7 and Chart 4.8 (see next page) are almost identical to Chart 4.5.

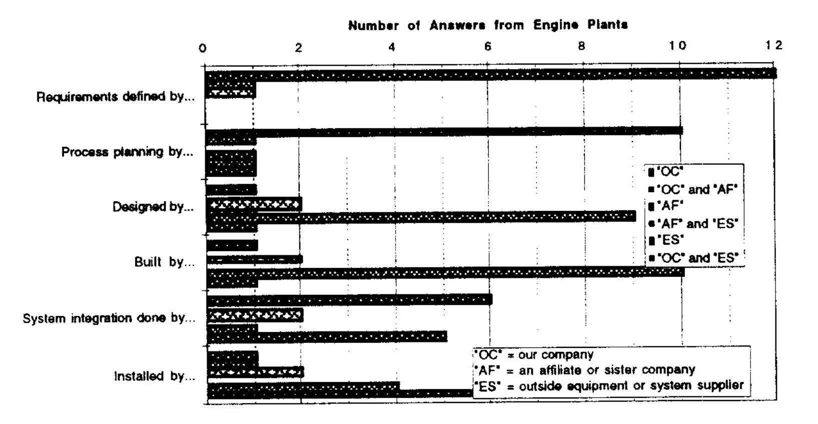
Acquisition Strategy for Existing *HEAD Assembly* Lines
(cf. Table C.19 on Page 43 of Questionnaire)



Acquisition Strategy for Existing *FINAL Assembly* Lines
(cf. Table C.19 on Page 43 of Questionnaire)



Acquisition Strategy for Existing *Engine TEST* Lines
(cf. Table C.19 on Page 43 of Questionnaire)



5. Quality

Tables C.20 and C.21 are about scrap and rework rates in machining and assembly departments of engine plants. The results had already been shared with the sponsors of the IMVP Engine Plant Study at prior occasions.

Quality performance measures

The following paragraphs correspond to data from Table C.22 of the questionnaire.

Customer satisfaction index

Only very few engines plants had such data available, but for those which did, there are always around 80% of satisfied customers after 12 months (concerning engine quality).

"Initial" engine quality

These numbers, which are plotted on Chart 5.1, indicate the fraction of finished engines which come back from the vehicle assembly plant to the engine plant. For half of the cases, fewer than 0.05% of engines are returned from the assembly plant (this is the overall median value). There are large variations, particularly when one looks at the location of manufacture of engines: *for our sample* (which concerns 17 data points in this case), **Europe is the place where most of the poorer-quality engines are built** (compared to North America -- we do not have much data about Japan).

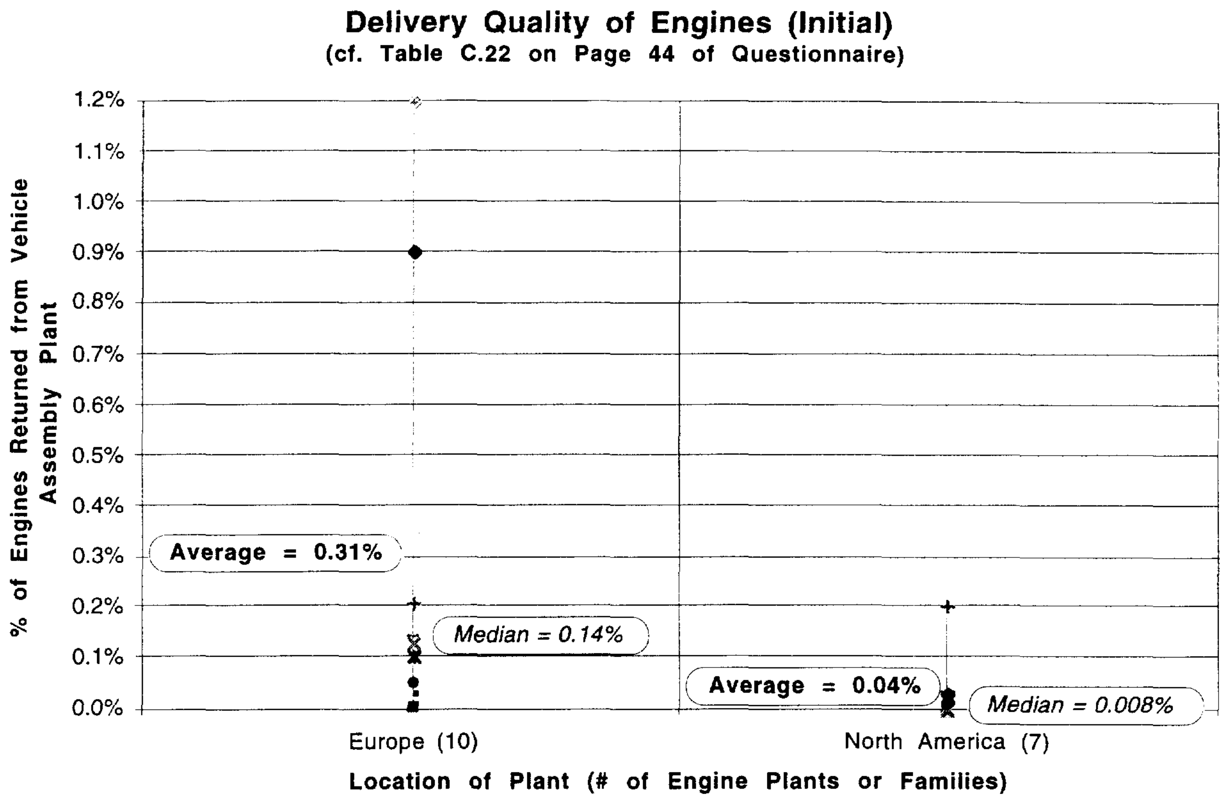
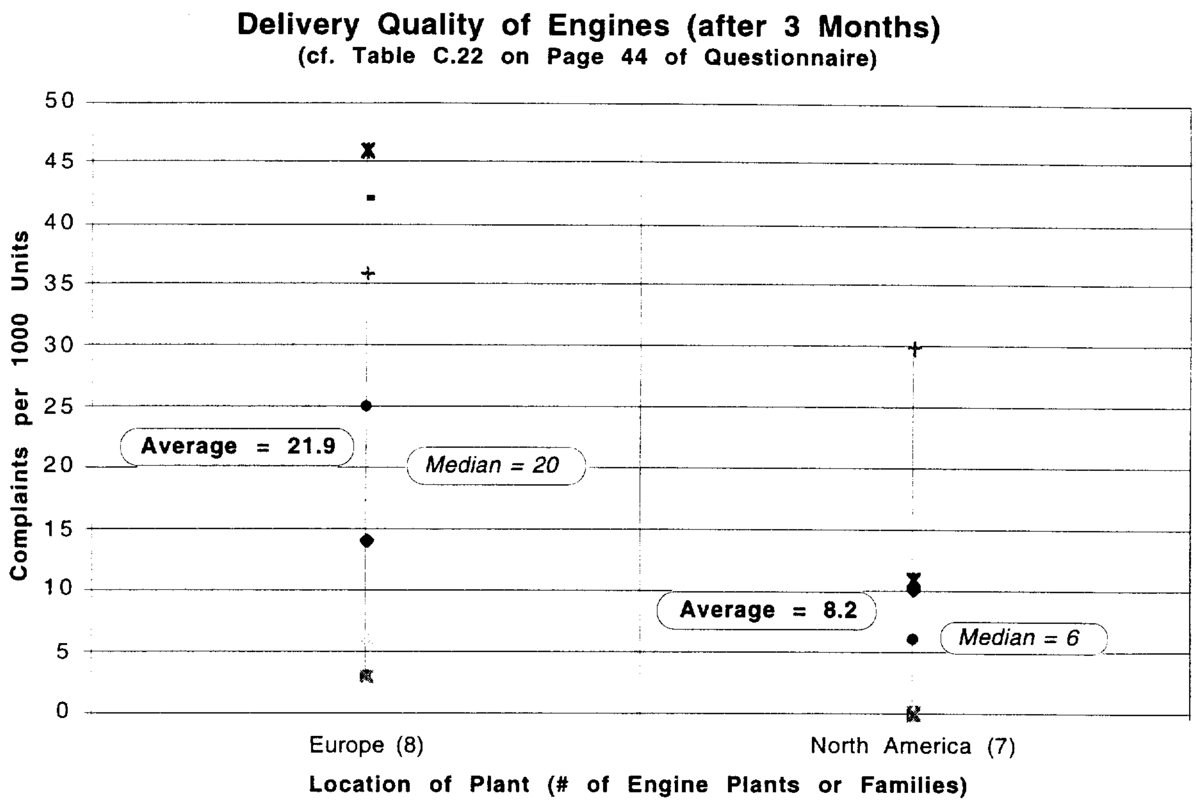


Chart 5.1

Evolution of engine quality data

As shown by Chart 5.2 and Chart 5.3, the difference of quality results between European and North American engine plants still exists when one looks at quality measures *once* the engines are installed in vehicles. Indeed, we have data about the number of complaints per 1000 engines, 3 months and 12 months after delivery... and in both instances, the average *and* median **numbers of complaints are much higher for engines made in European plants**. However, we should keep in mind that our sample of North American engine plants does not comprise that many facilities.



Delivery Quality of Engines (after 3 Months)
(cf. Table C.22 on Page 44 of Questionnaire)
Complaints per 1000 Units
50
45
40
35
30
25
20
15
10
5
0
Average = 21.9
Median = 20
Average = 8.2
Median = 6
Europe (8)
North America (7)
Location of Plant (# of Engine Plants or Families)

Chart 5.2

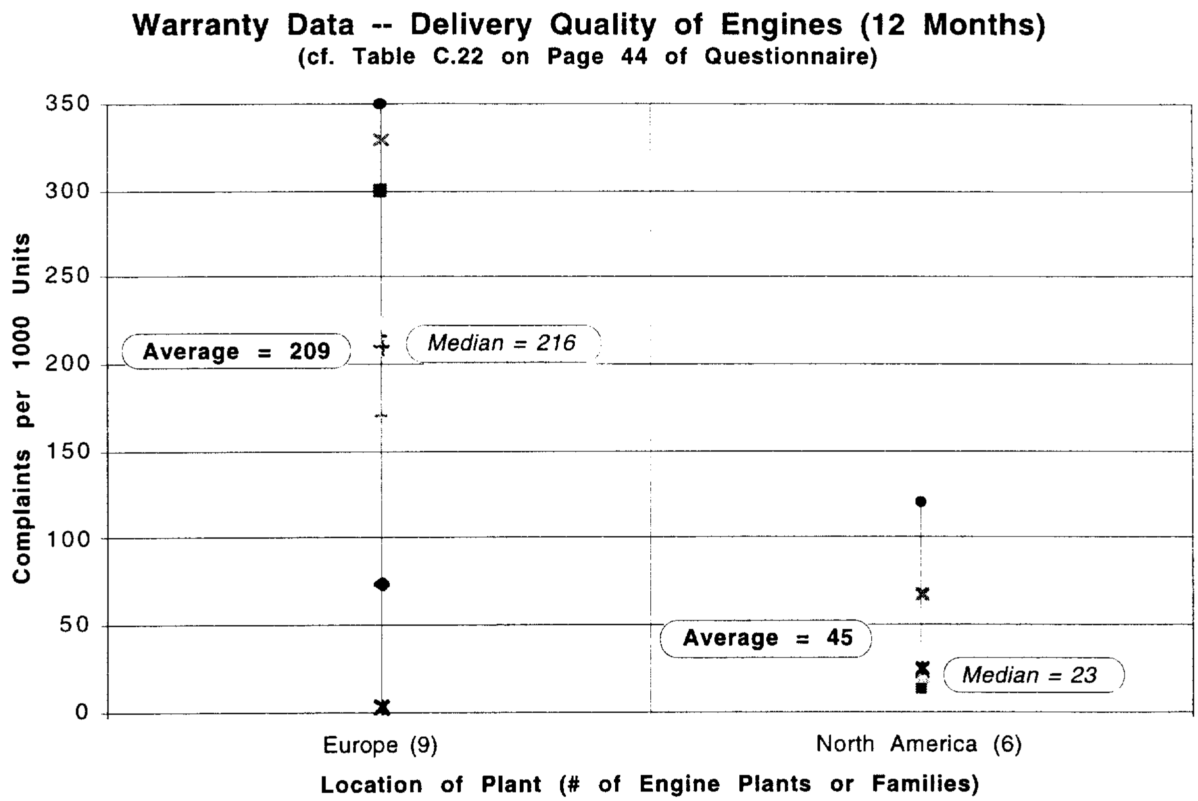


Chart 5.3

We thought that it might be interesting to see how these values evolve over time, so we plotted on the same graph the number of complaints per 1000 engines, 3 months and 12 months after delivery. In all cases, as time goes by, the number of customer complaints about engine quality increases largely, by an average factor of around 4 (which is also the ratio between 12 months and 3 months). See Chart 5.4 and Chart 5.5 for more details. So, 3-month quality data is a decent predictor of 12-month quality data, but, as we shall see in a later section, having a longer hot test duration does not necessarily help uncover engine-related complaints occurring after the car is delivered. On Chart 5.5, we also give an indication of where the Japanese engines stand: our answers only concern two engines (including one made in a U.S. transplant) and quality numbers 3 months after delivery are quite good, but we do not have data for 12 months after delivery.

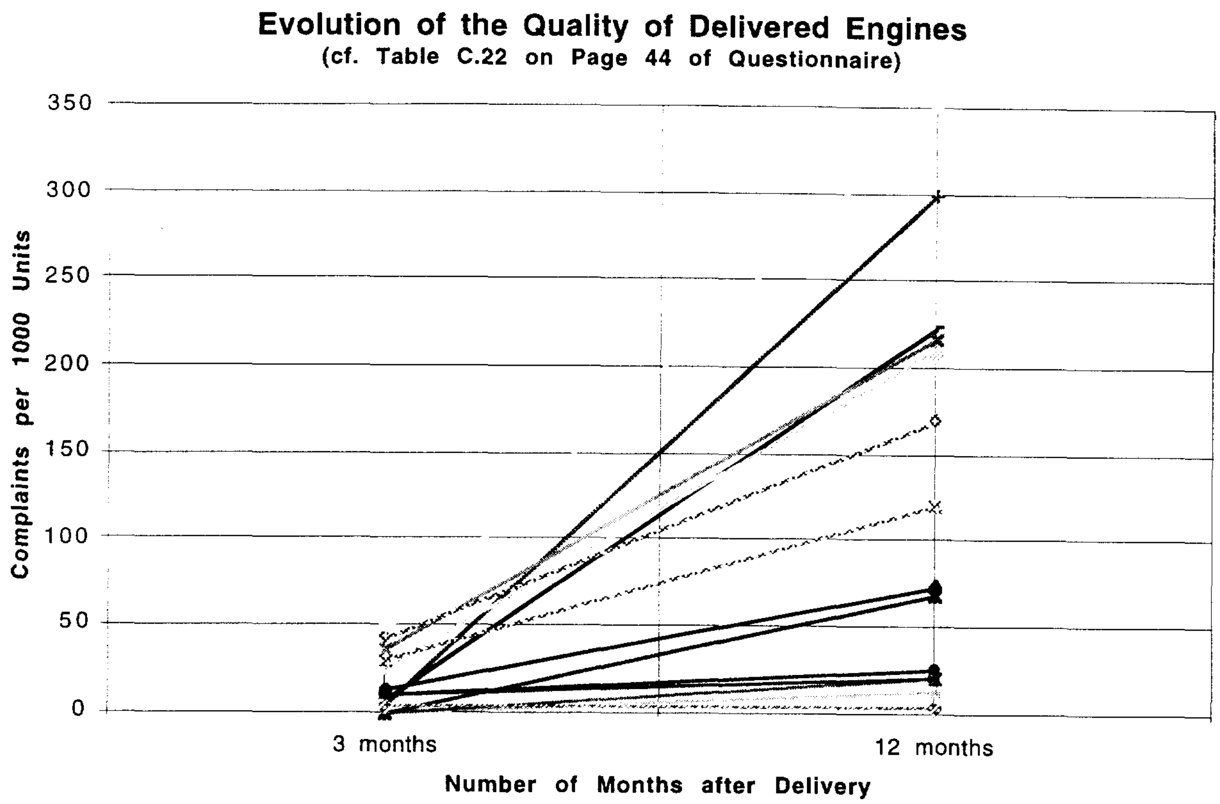

Evolution of the Quality of Delivered Engines
(cf. Table C.22 on Page 44 of Questionnaire)
350
300
250
200
150
100
50
0
Complaints per 1000 Units
3 months
12 months
Number of Months after Delivery

Chart 5.4

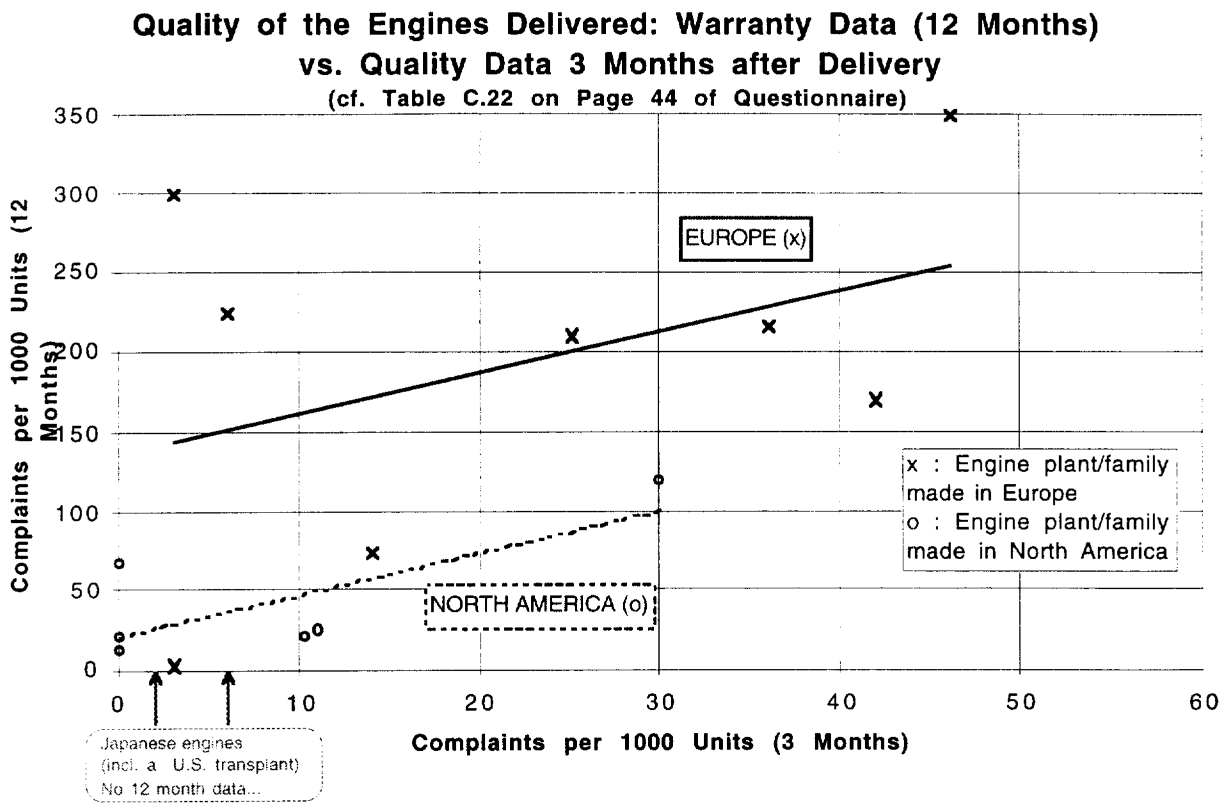


Chart 5.5

Reliability of engines

The metric used to assess the reliability of engines is the number of breakdowns per 1000 units, on a yearly basis. Although we have fewer answers from engine plants to this particular question, the results are plotted on Chart 5.6 (by region of manufacture): in most instances, there are **between 0 and 5 breakdowns per 1000 engines per year**.

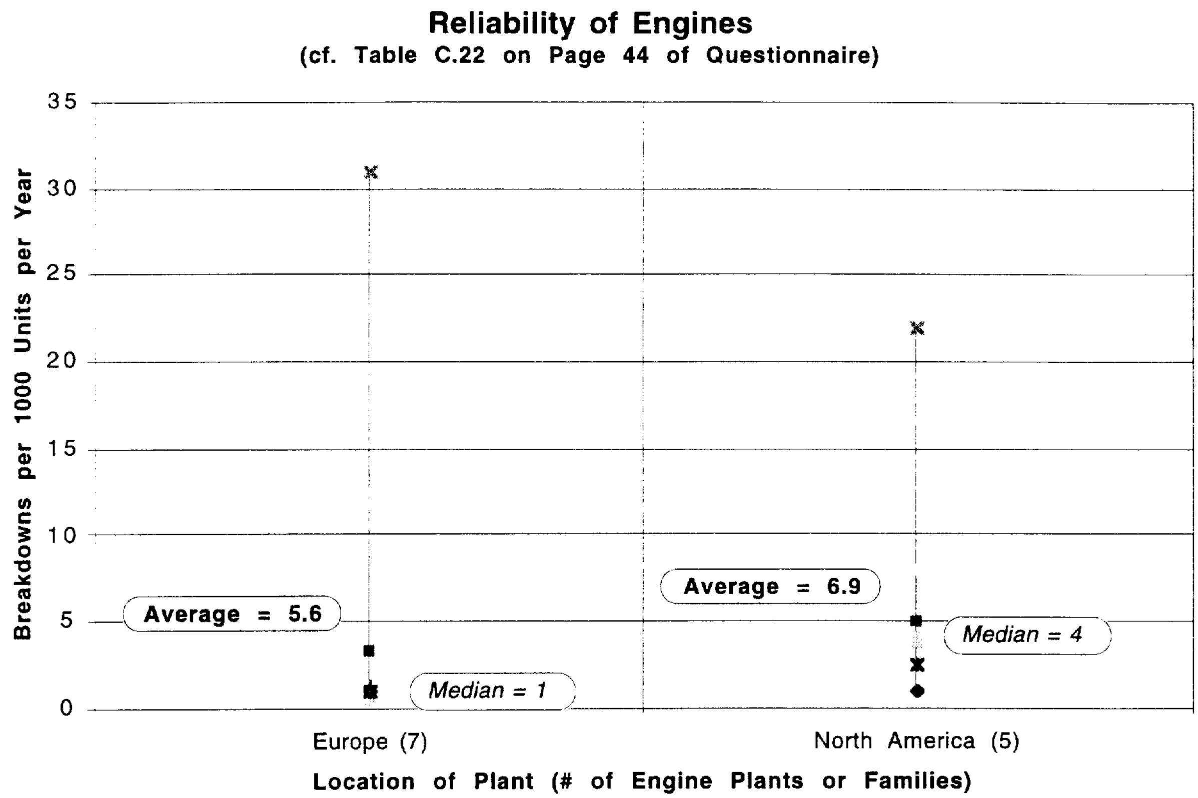


Chart 5.6

Long-term quality

We do not have enough data from the questionnaires we got back, in order to perform any kind of analysis on this subject. Apparently, information about long term quality was not often made available to the respondents.

Comparison with J.D. Power engine quality data

The 1995 Engine Quality Report℠ from J.D. Power & Associates determines engine plant quality by measuring the number of "things gone wrong" (per 100 engines) over the first year of vehicle ownership by customers *in the U.S. market.* A series of engine-related problems which have been encountered by customers are taken into account, each with equal weight; the study uses vehicle identification numbers of the vehicles surveyed to trace back the manufacturing plant of the engine. There are only 9 families of engines which are common to the J.D. Power study and to our survey. We are **unable to correlate** their engine quality results with any of the measurements that we have (whether it is the reliability, or the quality of engines 3 or 12 months after delivery).

Quality data collection

In the questionnaire, there is also some information about *how* people in engine plants gather important data which are related to the quality of the manufacturing process.

Quality data collection: cf. part C.5.2 of questionnaire (pages 44 and 45)						
QC29	Are SPC (Statistical Process Control) data collected and displayed at the line or work station?					
	"YES"	13				
	"NO"	1				
	OTHER	"Some"				
QC30	What typical Cp and Cpk values are obtained?					
Typical Cp	1.33	9 answers				
	1.62	2 answers				
	1.85	2 answers				
Typical Cpk	1.0	1 answer				
	1.0 - 3.0	1 answer				
	1.1	1 answer				
	1.33	6 answers				
	1.41	1 answer				
	1.67	2 answers				
	1.85	1 answer				
			Number of plants responding...			
			"ALL"	"MOST"	"SOME"	"NONE"
QC31	What fraction of in-process data are collected automatically in real time?		0	2	12	1
QC32	What fraction of in-process data are sent electronically to a central data processing center?		0	1	7	7
QC33	What fraction of final test data are collected electronically in real time?		2	5	3	5
QC34	What fraction of final test data are sent automatically to a central data processing center?		0	3	4	8
QC35	Are field performance and warranty data sent to the plant?					
	"YES"	14				
	"NO"	1				

Table 5.1

- QC29: in almost all engine plants, SPC (Statistical Process Control) data are collected and displayed at the line or work station.

- QC30: in most cases, a typical Cp used is 1.33; this value also represents half of the answers about Cpk. Other answers given are indicated on Table 5.1.

- Questions QC31 through QC34 deal with data collection: we asked what part of in-process data and final test data are collected automatically in real time and are sent electronically to a central data processing center. Table 5.1 gives the number of answers obtained in each of four categories. The main conclusion is that, in a majority of cases, only a modest fraction of the data are gathered either electronically or automatically.

- Finally, engine performance and warranty data are sent to the engine plant in 14 out of 15 cases; thus, the engine plant can have some valuable feedback.

Design/manufacturing interaction

- QC36 is about the *kind* of access to design data that engine plants actually have. Answers were given by 13 plants. In 7 of them, there is absolutely no kind of CAD (Computer Aided Design) data which is available about the design of the engine. However, when CAD data does exist, it is mostly 2-dimensional rather than 3-dimensional. We checked that the use of CAD systems is *not* a function of the age of the engine plant or of the date when the manufacturing lines were last refurbished. The major conclusion from this question is that, for people in engine plants, the most frequently used means of access to engine design is clearly via **fax or hardcopy** (cf. Table 5.2).

C.5.3. Design/Manufacturing Interaction (p. 45)							
			"1" = most frequent				
			"2" = next most frequent...				
QC 36: Plant's access to design data							
	# of people saying:	"1"	"2"	"3"	"4"	"5"	Not answered
Fax or hardcopy		10	1				2
Computer text data		1	5	2	1		4
2D CAD		2	3		2		6
Wireframe 3D CAD				3	1		9
Solid model 3D CAD						4	9
QC 37: Most frequent time lap for exchange of info							
		Result					
Daily		3					
Weekly		7					
Monthly		3					
Yearly		0					
Less often		0					
QC 38: Most frequent time lap for design change							
		Result					
Daily		2	<== This is quite surprising: question misunderstood?				
Weekly		2					
Monthly		6					
Yearly		3					
Less often		0					
Table C.23: Reasons for design changes (in %)							
		Average (%)	Min (%)	Max (%)		# of answers	
Worker suggestions		7.3	2	20		13	
Changes to fix production problems		11.9	5	50		13	
Design dept. changes to fix design or perf. probs.		22.0	5	50		13	
Design dept. changes to improve engine		27.7	8	60		13	
New variant to meet market needs		11.7	0	30		13	
Customer suggestions		5.0	0	30		13	
Dealer suggestions		3.0	0	10		13	
Changes in law or regulations		11.5	0	23.8		13	
NB. I checked that each plant's data always add up to 100%							

Table 5.2

- With question QC37, we wanted to know how *often* information is exchanged between the engine plant and the engine design department. It turns out that in a majority of cases, **weekly exchanges** are most frequent. Other plants said that most of the time, they were exchanging design data on a daily or monthly basis. Please see Table 5.2 for further details.

- QC38 asks about the frequency of **design changes**. The kind of answer which was most often given by engine plants is "**monthly**". As shown on Table 5.2, there are plants for which design changes occur only yearly, while in other cases, it can be weekly or even daily! In light of this, we can wonder whether the question was always understood correctly by the respondents...

Reasons for design changes

Table C.23 asks about the estimated relative distribution (as a percentage) of the reasons for which there have been design changes of engines in the three years before 1995. Roughly **half of the occurrences of design changes come from the engine design department** in order to improve the engine and to fix design or performance problems. Three other categories (namely: changes to fix production problems, new variant to meet market needs, changes in law and regulations) each represent between 11% and 12% of the reasons for which there have been design changes in the engine plants surveyed. For more details about the results, please refer to Chart 5.7 or to Table 5.2.

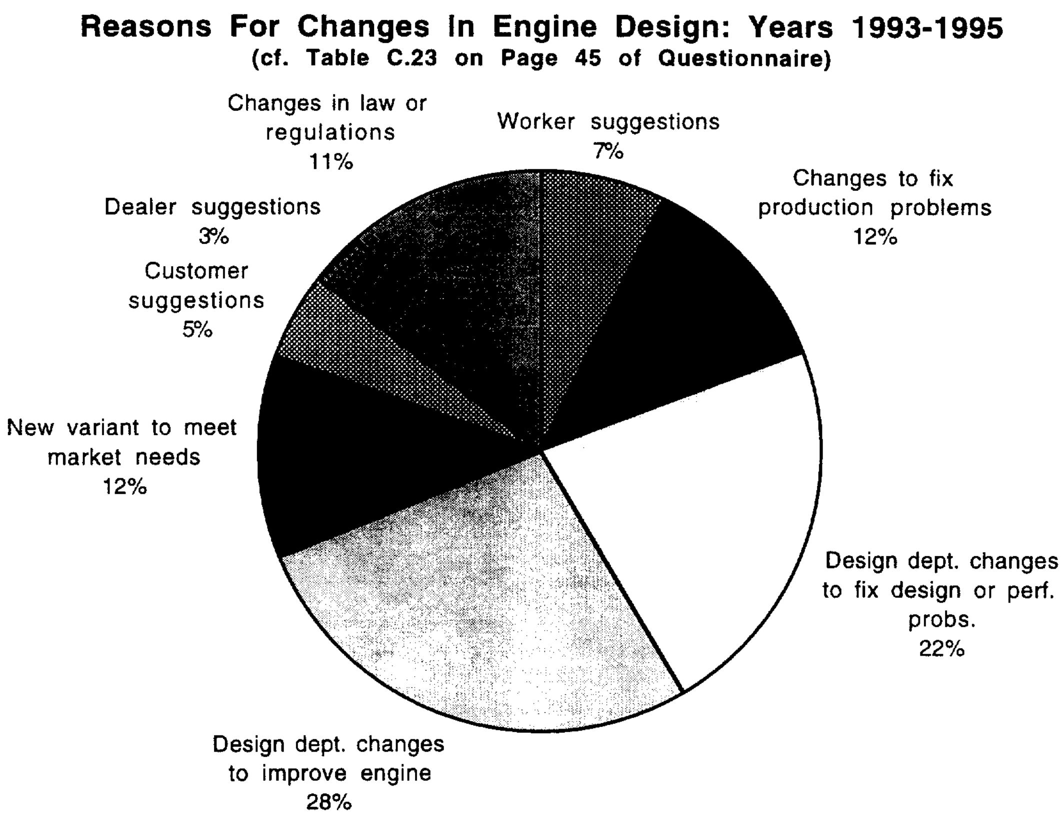


Chart 5.7

By looking at the "Min." and "Max." columns on Table 5.2, one can realize that, for each of the categories, the percentage value can vary quite a lot from one plant to another. Chart 5.8 also shows this variability in fuller details, for the engine changes which have occurred because of *changes in law or regulations*; this factor seems to be relatively less important in North America than in the European engine plants which are not the most modern ones, according to the information from the 13 plants which answered to this question.

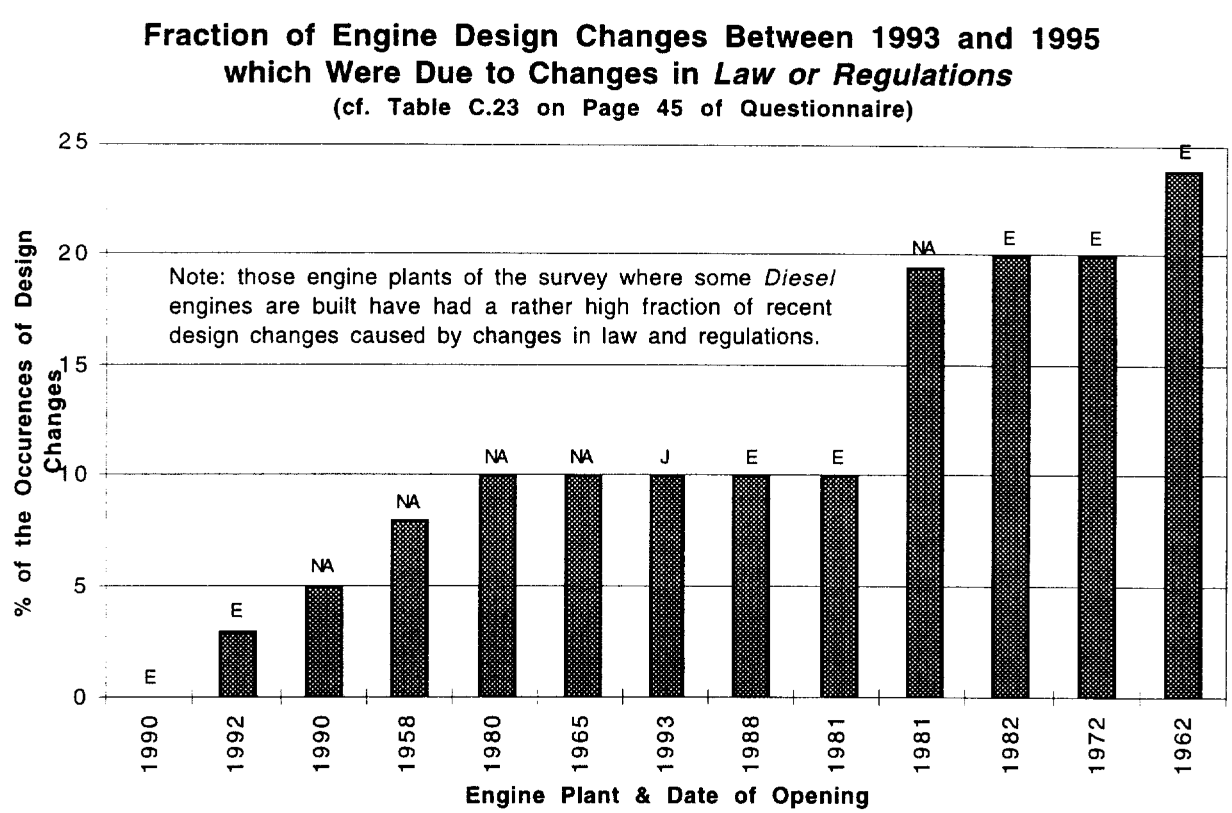


Chart 5.8

Testing of engines in engine plants

Hot testing

Table 5.3 reports the answers to questions QC39 through QC47 -- some graphs and other tables complement the information.

Testing: cf. part C.5.4 of questionnaire (page 46)						
QC39	Is <u>each</u> engine *hot* tested?			How long?		
		"YES"	14	From 45 seconds to 18 minutes		
		"NO"	2	cf. chart in worksheet "Graph QC39,40,42"		
QC40	Is a <u>sample</u> of engines *hot* tested? What percent of engines?					
	Those two plants which hot-test only a sample do it for 50% or 80% of engines					
	cf. x-axis of the chart in worksheet "Graph QC39,40,42"					
QC42	What percent of engines pass the *hot* test the first time?					
	From 93% to 100%					
	cf. data labels of chart in worksheet "Graph QC39,40,42"					
QC43	Is each engine *cold* tested?					
		"YES"	6			
		"NO"	10			
QC44	What percent of engines pass the *cold* test the first time?					
	86%, 96%, 96%, 99%, 99.4%, 99.9%					
QC46	Is testing done by the same people who do the dressing of engines?					
		"YES"	2			
		"NO"	13			
		Other: "yes" in process, "no" in final test				
QC47	Is the engine control unit married to engine before test and kept with it after test?					
		"YES"	2			
		"NO"	14			

Table 5.3

- QC39: all engine plants conduct hot tests; all but two of them conduct hot tests for *every* engine which they produce. The **duration** of the hot testing **varies** from 45 seconds to 18 minutes, as shown on Chart 5.9. The (few) engines of our sample which have aluminum blocks are among those being hot-tested for longer periods (10 minutes and 15 minutes), but they are not the only ones.

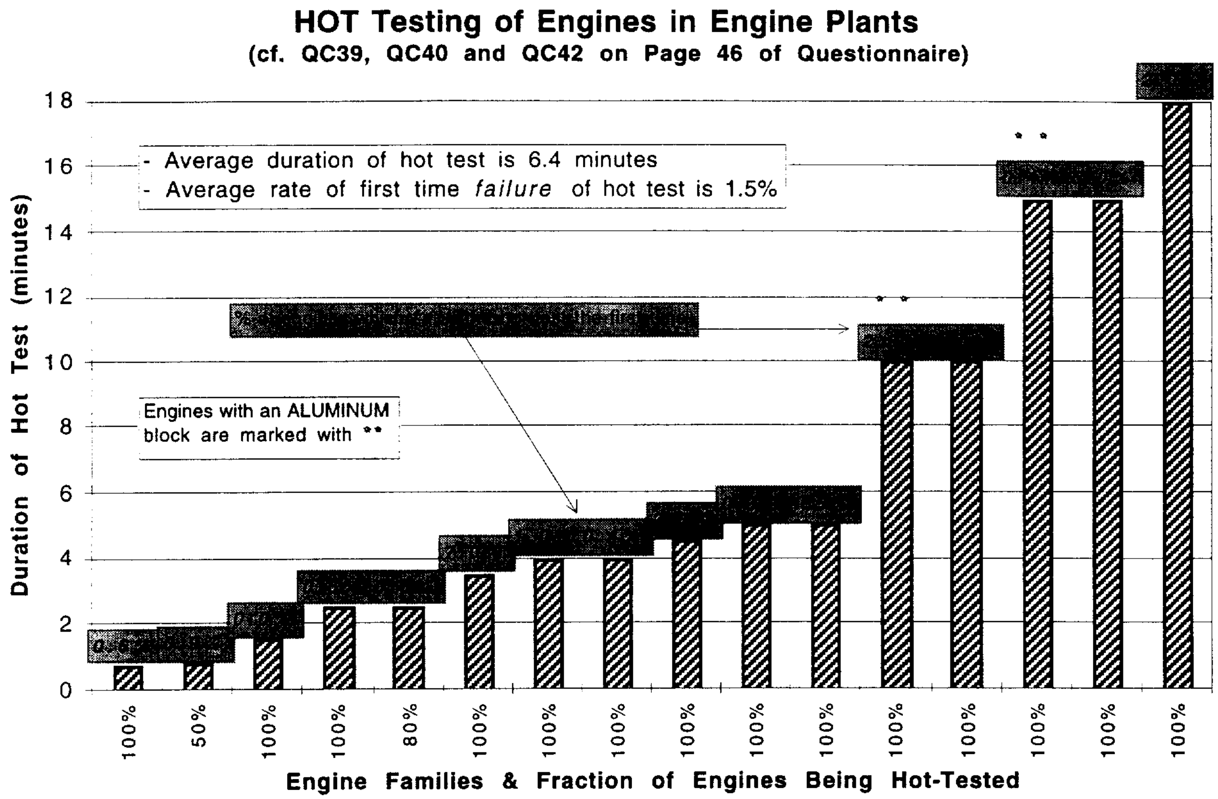


Chart 5.9

- QC40: in the two engine plants where only a *sample* of the engines are hot-tested, this fraction is 50% in one case and 80% in the other case.

- QC41: description of the hot test. Answers from our sample indicate that there are *many* methods in place in the automotive engine plants.

- QC42: the percentage of engines which *pass* the hot test the first time is between 93% and 100%. Chart 5.9 indicates the fraction of engines which *fail* the hot test. We did check that there is **no correlation between the duration of the hot test and the rate of first-time failure at this test**.

By looking simultaneously at hot test results and at engine quality data, we were not able to correlate either the length of hot testing or the rate of failure, with number of complaints per 1000 engines after 3 or 12 months of use (cf. Chart 5.10 and Chart 5.11). Also, there is no link between the duration of hot testing and either initial engine quality or engine reliability (cf. Chart 5.12 and Chart 5.13). Hence, we can conclude that the types of **problems that are detected during hot testing** at the end of the engine manufacturing process **are different from the types of**

problems which occur to engines during the time when they are operated by vehicle owners; like we stated in an earlier portion of this section about quality, a longer hot test does not help uncover engine-related problems happening after the car is delivered. Hot testing can reveal problems associated with the quality of purchased components and with the manufacturing process exclusively, while the customer quality data (complaints per 1000 engines) also comprise problems which have to do with wear and tear, driving conditions etc...

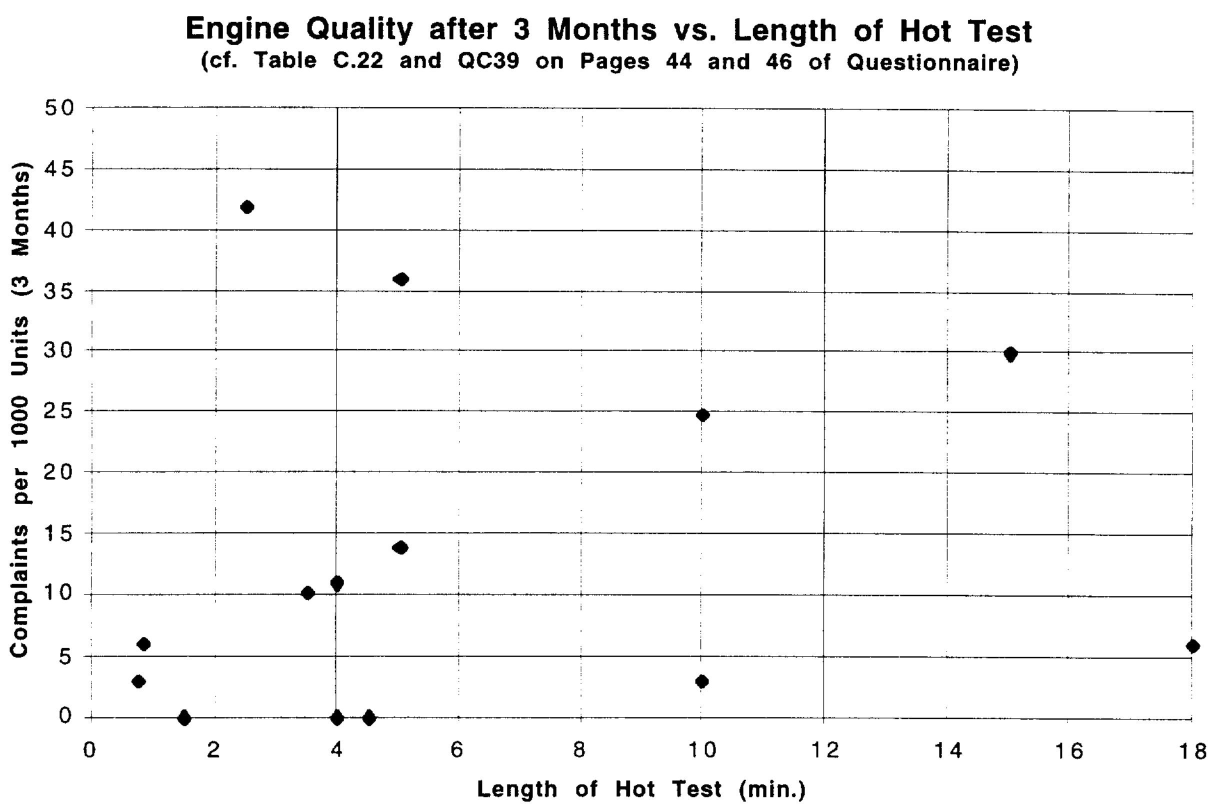


Chart 5.10

Engine Quality after 12 Months vs. Length of Hot Test
(cf. Table C.22 and QC39 on Pages 44 and 46 of Questionnaire)

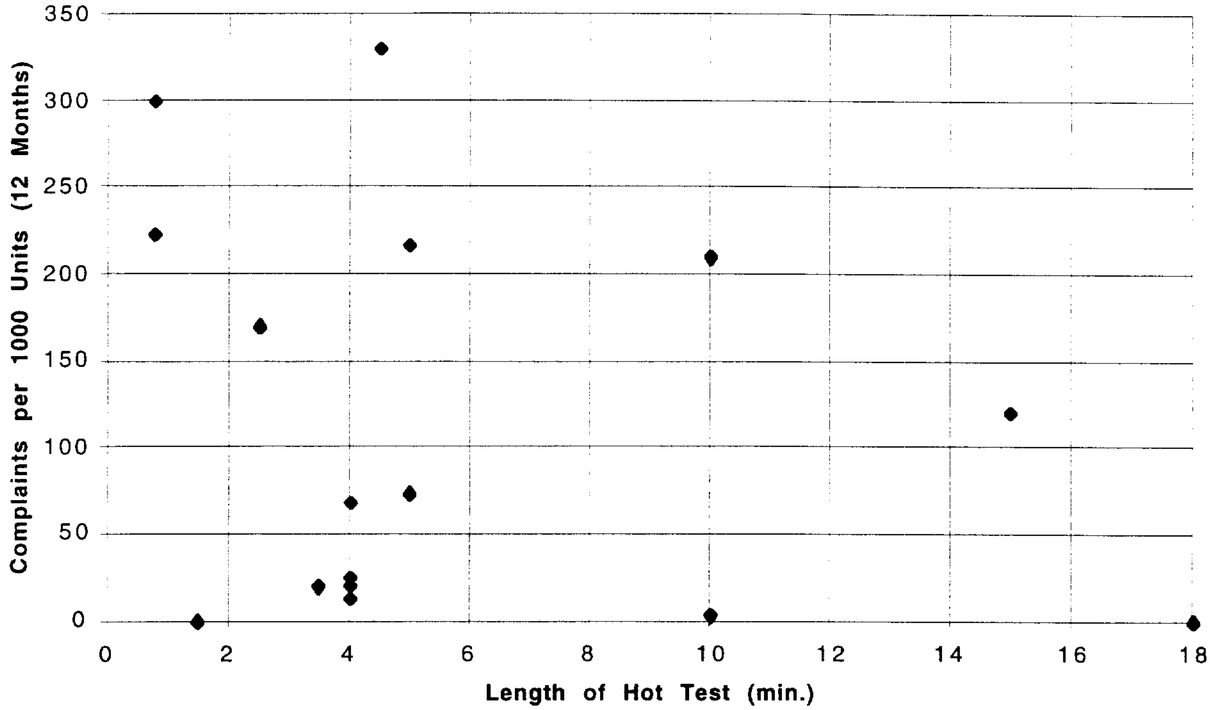


Chart 5.11

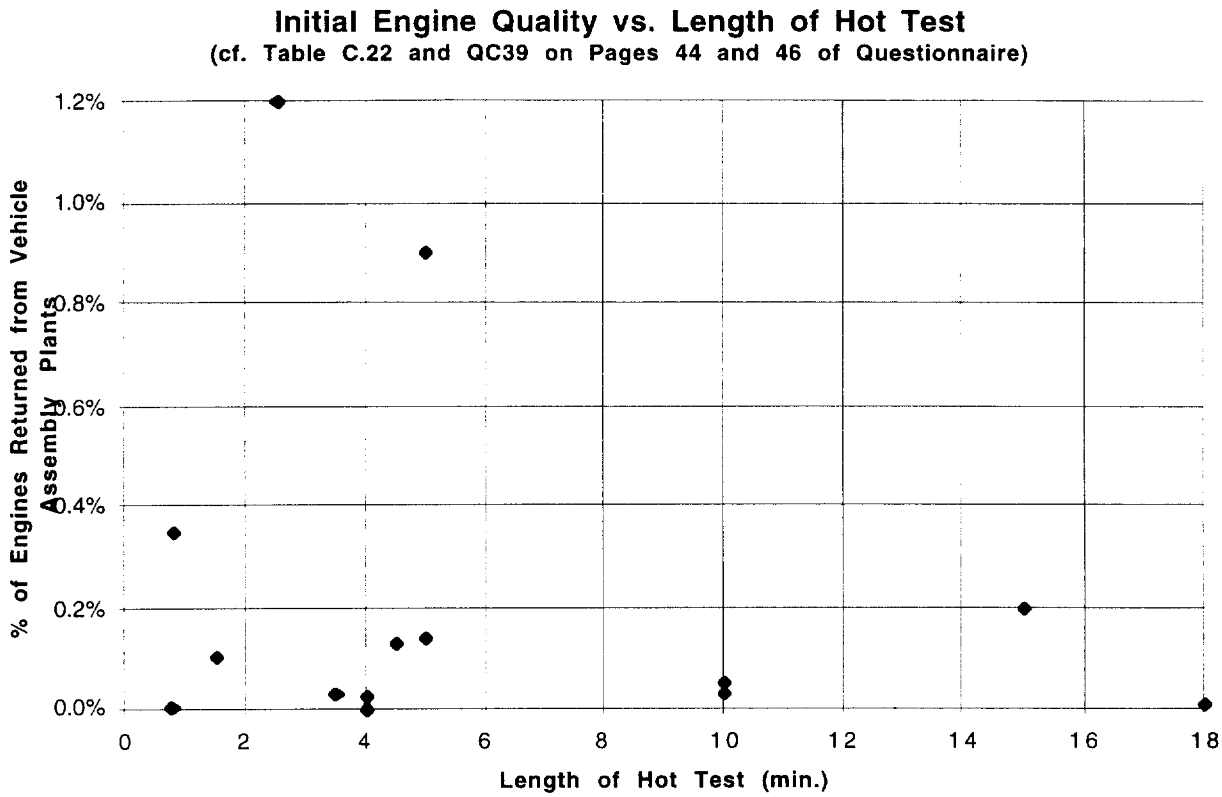

Initial Engine Quality vs. Length of Hot Test
(cf. Table C.22 and QC39 on Pages 44 and 46 of Questionnaire)
% of Engines Returned from Vehicle Assembly Plants
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
0
2
4
6
8
10
12
14
16
18
Length of Hot Test (min.)

Chart 5.12

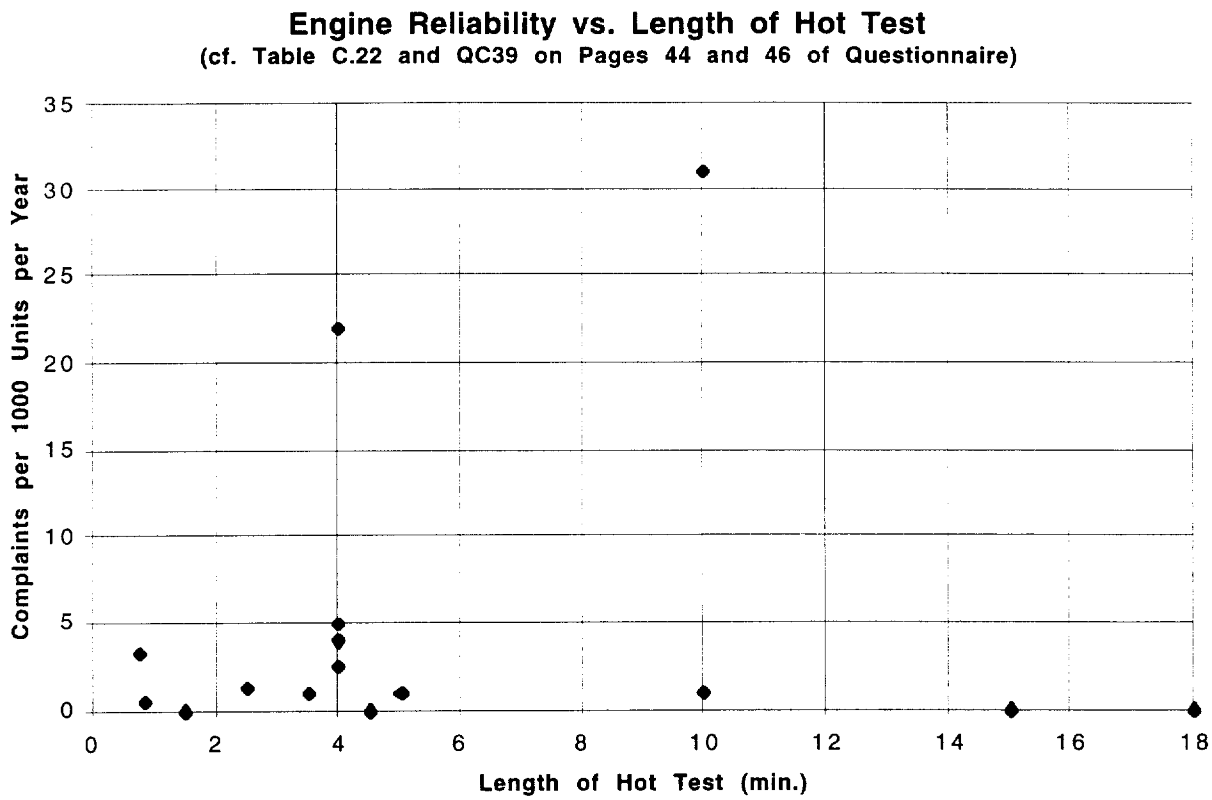


Chart 5.13

Cold testing:

- QC43: contrary to hot testing, cold testing of engines is done only in a fraction of engine plants (6 out of the 16 from our sample).

- QC44: when cold testing is conducted, the percentage of success the first time ranges between 86% and almost 100% (most of the values are above 96%: cf. Table 5.3).

Other information about testing:

Data about the kind of **problems** found in final testing of engines (cf. Table C.24 of the questionnaire) are presented in Table 5.4.

Table C.24	Problems found in final testing (cf. page 46 of questionnaire)			
	Listed below are the answers given by the respondents			
	electrical connections	bad injectors	balance	fixing of TBI unit
	power contribution	bad spark plugs	timing	wrong ignition sequence
	vacuum		leaks	wrong time belt tension
	injector cable not connected	water and oil leakage	missing thermostat joint	oil leaks
	impulse sensor camshaft not OK	diesel fuel leakage	loose bolts	abnormal noise
	petrol tube loose	injection default	leak in water pump	electrical connection, missing part, etc.
	assembly faults	leaks	water leak	
	leakage	loudness/noise	oil leak	
	component faults from vendor	assy errors	function error	

Table 5.4

- QC45 asks about some of the important **in-process tests** performed *before* any hot or cold testing of the engine. Table 5.5 gives a list of the different answers gathered via the survey of engine plants. There is no tendency towards shortening the duration of hot tests in more modern engine plants, as shown by Chart 5.14. Obviously, people in engine plants desire to eliminate as many non-necessary steps as possible, especially those which do not add any value to the engines being produced: however, when it comes to in-process testing, the quest for quality must prevail, and there is not much preventive error-proofing that can be done with problems involving two or more parts (like tasks where leaks are checked for in the lubricating or cooling systems at various stages of machining and assembly). [Note: on the contrary, for problems of selective assembly, quality, or dimensioning which involve only one part, error-proofing is feasible, but one must be particularly secure about the quality of components from ones supplier and from oneself!]

QC45	Important in-process tests which are done before hot or cold tests (cf. page 46 of questionaire)		
	Listed below are the answers given by the respondents		
	2 rolling tests	torque to turn after crank, cam & timing chain	cranking torque - short block
	vibration	torque to turn after piston & rod	leakage oil seal
	2 leak tests: crankshaft and head valves		
	torque to turn, cam+crank	torque to turn	leak test of short block
	torque to turn, after piston	fastener torque	manual test of crank floating
		rear seal air test / cam-crank end game	
	leak test	cranshaft bearing detection, rotation of crank in block	leaks in water and oil galleries
	automatic screwing stations	rotation of crank, rod and pistons	
		piston height, sealing, valve leaks	
	leak oil, water, fuel	leakage test (block and head)	axial execution measuring
	crank torque		friction performance
	gear backlash		bolt torque / angle control
	(too many tests listed to indicate here)	leak in connections	product audits
		engine bad function	process audits
		bad assembly of principal harness	

Table 5.5

There Is No Tendency To Shorten The Duration Of Hot Testing In More Modern Automotive Engine Plants
(cf. QC41 on Page 46 of Questionnaire)

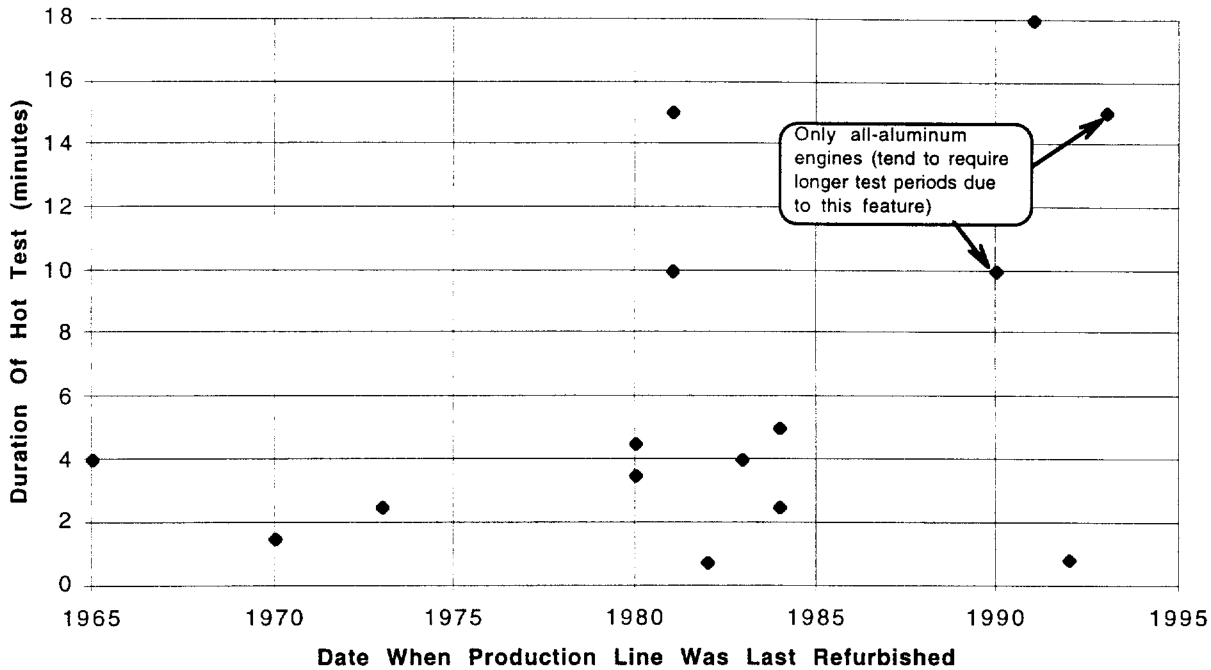


Chart 5.14

- QC46: it clearly appears (cf. Table 5.3) that, **in general, the people affected to engine testing are not the ones who work on the engine dressing line** (except in a few plants).

- QC47: the only two engine plants where the engine control unit (ECU) is married to the engine before the test and kept with it after the test are the Japanese facilities from our survey. ECUs are not just a function of the engine variant; they are programmed according to the car model (and its options) to which the engine will be fitted. Even though sequencing is such that the engines are, in most cases, dedicated to a particular vehicle when they are undergoing their final dressing, there is no need to send the engine with an ECU to the vehicle assembly plant, because under the hood in the engine compartment of the car, the ECUs are generally not fixed on the engine itself, in order to avoid vibration or temperature problems (among other things). [However, we can imagine that in some future applications, a well-insulated engine control unit will increasingly become an integral part of the air/fuel intake system, as suggested by the recent Ecotec inline-3 gasoline engine from Opel and by integrated intake module concepts from companies like Siemens or Bosch.]

Critical technologies and technical factors for high quality production

What are critical engine manufacturing technologies? Table C.27 of the questionnaire tries to give some elements of response. Out of 16 engine plants for which we have answers, 11 did list a few of the casting, machining, assembly or testing technologies which they see as critical for the high performance and quality of engines. In Table 5.6, we indicate the results: one can see that some respondents gave "more" information than others. Overall, **honing of the cylinder** liner is often cited, as it constitutes a crucial operation (issues are the machining process itself and surface treatment). Technologies for **camshaft** finishing and treatment are also among those which are critical, according to our respondents. Crankshafts and crankshaft bearings, along with connecting rod cracking, do constitute other areas of interest for critical technologies, but to a smaller extent than cylinder honing and camshaft manufacturing. One can notice that the answers from this table almost all concern technologies which find an application in the *machining* departments of engine plants, so the assembly and testing sections seem to be less technologically-intensive.

Table C.27 on Page 48: Critical Technologies (We have answers for 11/16 engine plants)			
Question:	*" **What critical** casting, machining, assembly or testing **technologies** do you have in the plant that give your engines high performance and quality, and **who supplied these** technologies?"*		
Plant #	Plant 1	Plant 3	Plant 5
technology	no touch piston handling	cylinder block honing	TPS - kanban, JIT, mistake proofing, built-in quality
advantage	reduce aluminum piston handling damage	low oil emission, high lifetime of engine	flexibility, good utilization of human resources
made by...	bought from supplier	bought from supplier	**"made by" [our] company**
	non contact piston gaging	finising of crank and camshaft	
	reduce piston damage, increase precision	noise and lifetime	
	bought from supplier	bought from supplier	
	dual wheel camshaft lobe grinders	hardening of camshaft	
	reduces facility & tooling dollars	low wear, life time	Plant 6
	bought from supplier	bought from supplier	
			alu casting for cylinder head
			cost, quality
			bought from supplier
			CNC turn-broaching for crankshaft
	Plant 2	Plant 4	flexibility, quality, better machine output
			bought from supplier
	tungstene inert gas for cam treatment	block high speed cylinder bore	microfinishing for crankshaft
	cam surface hardness	high capacity	quality
	bought from supplier	bought from supplier	bought from supplier
	cylinder honing	con rod cracked	100% measuring of cam's form
	surface state	fewer machining steps, better quality	quality
	bought from supplier	bought from supplier	bought from supplier
		assembly: leak test, end function test	cast iron cams hardened by WIG-melting and nitrurized
		in-line testing capacity	cost, quality
		bought from supplier	bought from supplier

Table 5.6 (i)

Table C.27 on Page 48: Critical Technologies

*Question: "**What critical technologies** do you have in the plant that give your engine high performance and quality, and **who supplied these** technologies?*

Plant 7	Plant 9	Plant #
honing of cylinder bore	hone cylinder bore	technology
minimize wear and oil use	emergency running lubrication, low oil consumption	advantage
bought from supplier	**made by an affiliate**	made by...
laser welding of bucket-type tappets	roll crankshaft bearing	
improved process security and quality, reduced cost	increase durability	
made by an affiliate	bought from supplier	
machining of valve fitting/seating in the cyl. head		
low emissions; higher precision minimizes friction		
weight-reduced bucket-type tappet		
reduced friction work	Plant 10	
bought from supplier		
plasma-nitrating	assembly	
independence of particular geometry; environmentally-friendly	high quality	
bought from supplier	**made by an affiliate**	
tension-controlled screw connections		
process security in maintaining the torque		
bought from supplier		
connecting rod cracking		
	Plant 11	
	clean down	
Plant 8	no cleaner rub out	
	bought from supplier	
stitch boring		
better micro & size		
bought from supplier		

Table 5.6 (ii)

Who supplies these critical *manufacturing* technologies in the field of automotive engines? For the overwhelming majority of our answers, the technologies are **outsourced** to specialized companies (which are often small firms).

The results from Table C.28 give an indication of how a series of *technical* factors are "important" for the respondents from the engine plants surveyed. By "important", we mean "important in order to obtain high quality production" in the machining and assembly processes of engine manufacturing.

Chart 5.15 enables to tell which factors are most important for engine plants taken as a group. It is striking that **organizational factors**, such as maintenance policies and cleanness of the plant, are clearly regarded as **highly important** issues by all plants. By contrast, the results show that automatization and the extensive use of computer systems are not viewed as the ultimate solution to help obtain high quality engines. One could put such an opinion in parallel with the recent drop in interest and commitment for complex robotized lines in automobile factories: higher quality cannot be obtained just by installing more robots and many complicated machines.

Technical Factors for High Quality Production of Engines
(cf. Table TC 28 on Page 48 of Questionnaire)

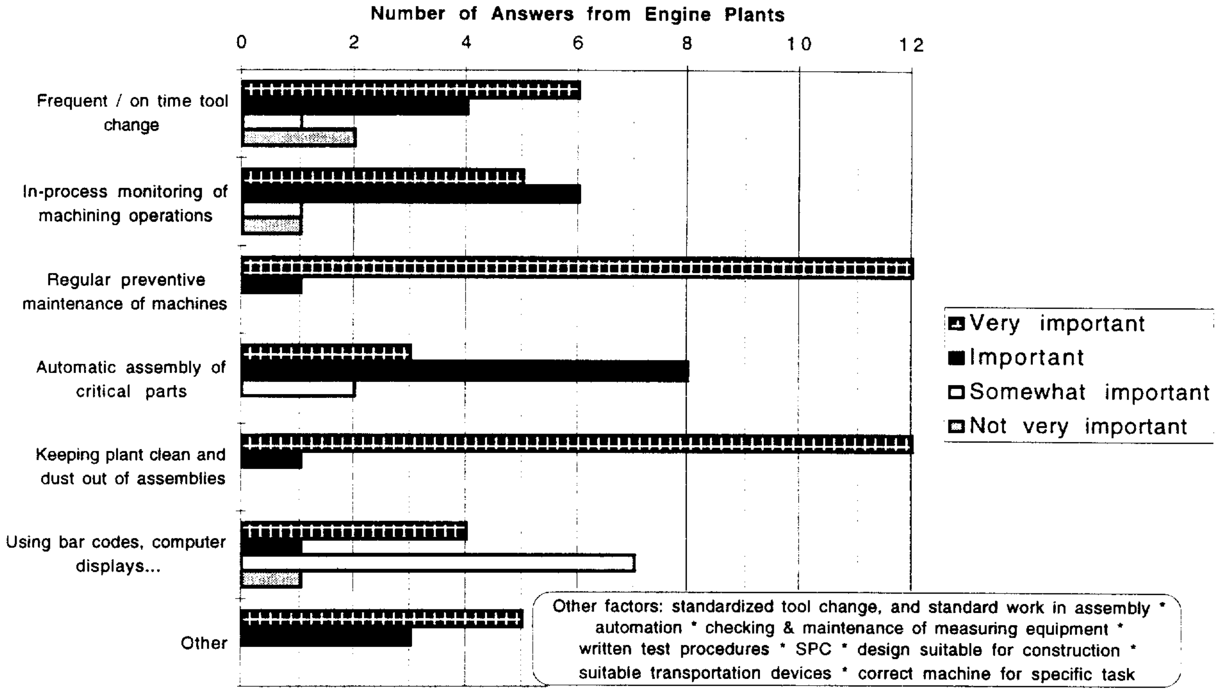


Chart 5.15

6. Information systems

The purpose of this section is twofold:

1. See to what extent information systems are currently in use in engine plants.
2. Learn about who can access the engine plant operating data.

Central and non-central information systems

Firstly, we asked about the capabilities of the **central information system**.

Chart 6.1 presents the number of positive and negative answers given by the different respondents concerning a dozen of functions. The most common tasks which are performed by the central information systems of engine plants are maintaining production orders and compiling production statistics. In a significant number of facilities, functions dealing with maintenance and statistics are also taken care of by the central information system.

Functions of *Central* Information System
(cf. Table C.29 on Page 49 of Questionnaire)

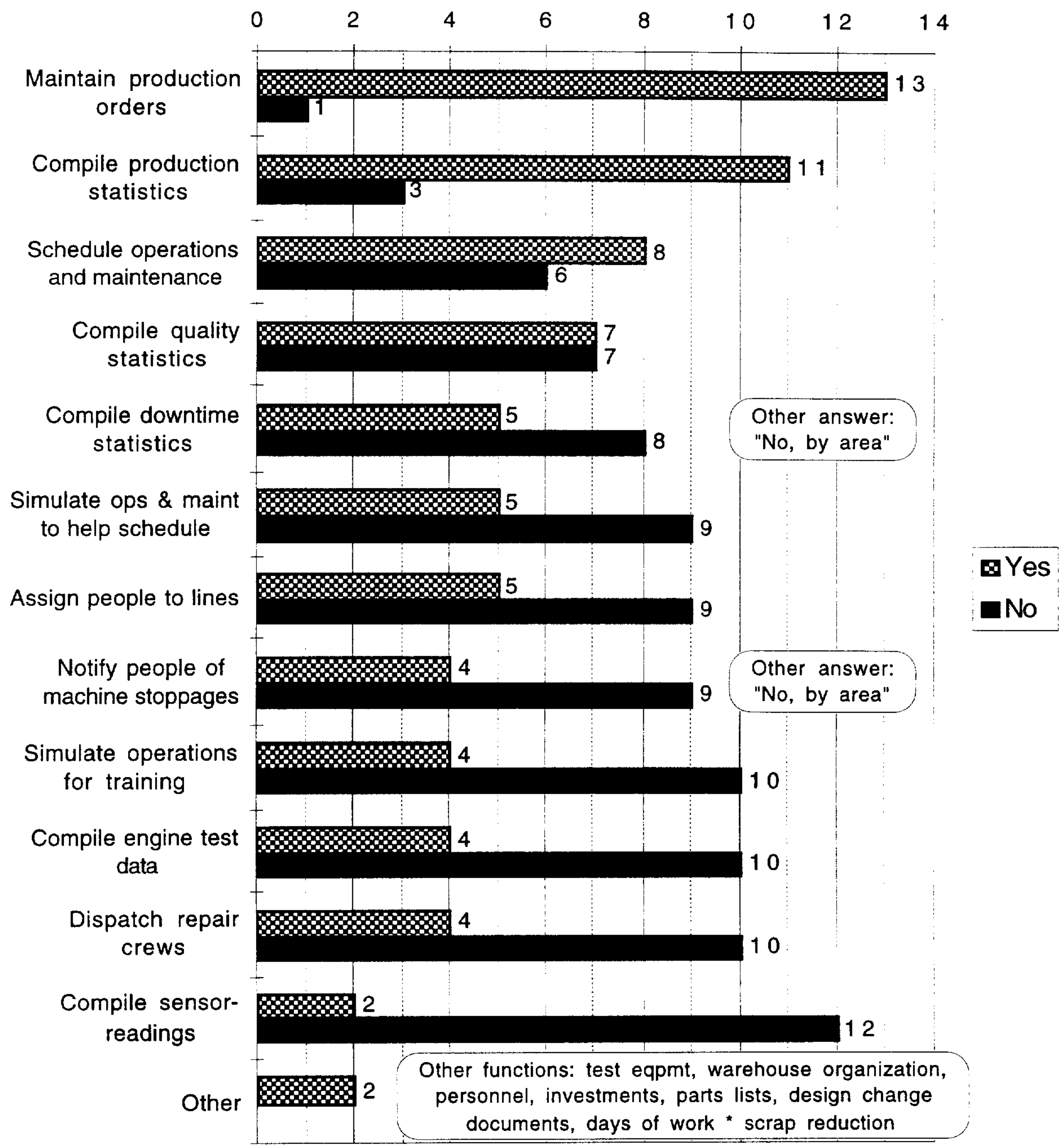


Chart 6.1

Secondly, we looked at those tasks which are handled by **non-central computer systems**.

It appears that these computers (which can be located on or near the plant floor) are much more used than the central computer system in order to compile data and statistics. These "local" computer systems are also the ones which people can rely on (in a majority of engine plants) to know about equipment problems and to deal partly with them (more details are on Chart 6.2).

We can observe that it is still quite rare in engine plants (only 4 cases out of 13 or 14 answers) that either the central or the non-central information system is used to actually give work instructions to people, like assigning workers to production lines, or dispatching repair crews.

Functions of *Non-Central* Information Systems

(cf. Table C.30 on Page 50 of Questionnaire)

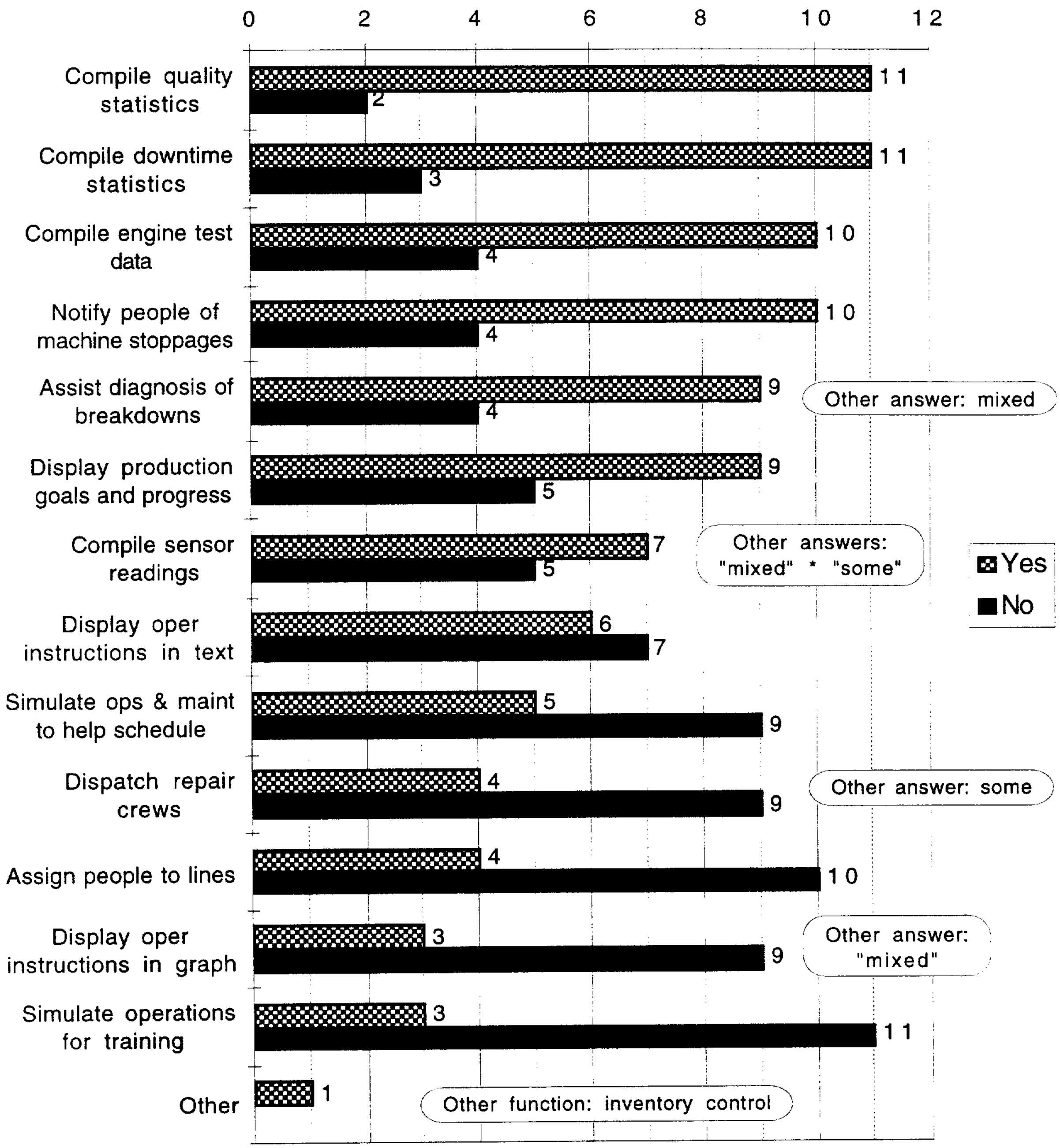


Chart 6.2

Access to engine plant operating data

In most instances, full access to plant operating data is not granted to all employees. Whether it is age, location or some other characteristic, we cannot find anything that distinguishes the 3 engine plants where full access is granted to all. Note: it may be that people who have access to the plant data do not necessarily consult this information. However, as shown on Chart 6.3, not allowing full access to all employees does not mean that the operating data can only be accessed by either salaried employees or by managers. On the contrary, it appears from the information of question QC50, that employees in engine plants can have access to a certain amount of operating data, most probably the one that directly interests their job.

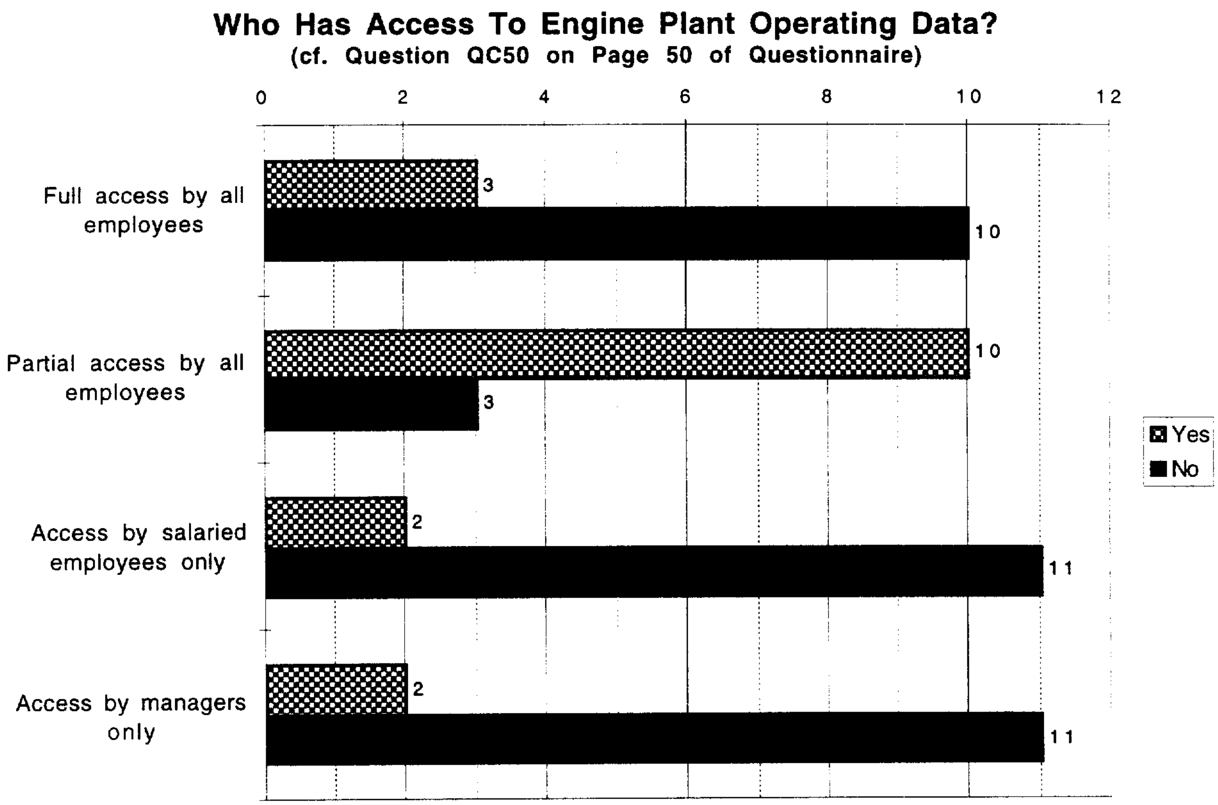


Chart 6.3

7. Accounting procedures and investment decisions

The data about the estimated value of several production lines of engine plants had already been used and presented to the sponsors of this study at prior occasions. The goal was to compare the capital productivity of the machining and assembly lines on a similar basis (i.e. by looking at the estimated value divided by production per shift).

Example of a recent major installation of equipment

Chart 7.1 summarizes the useful answers to questions in Part C.7.2 of the questionnaire. It deals with an example of a recent, major replacement of manufacturing equipment (such as a set of machines, a production line...) in the engine plants surveyed.

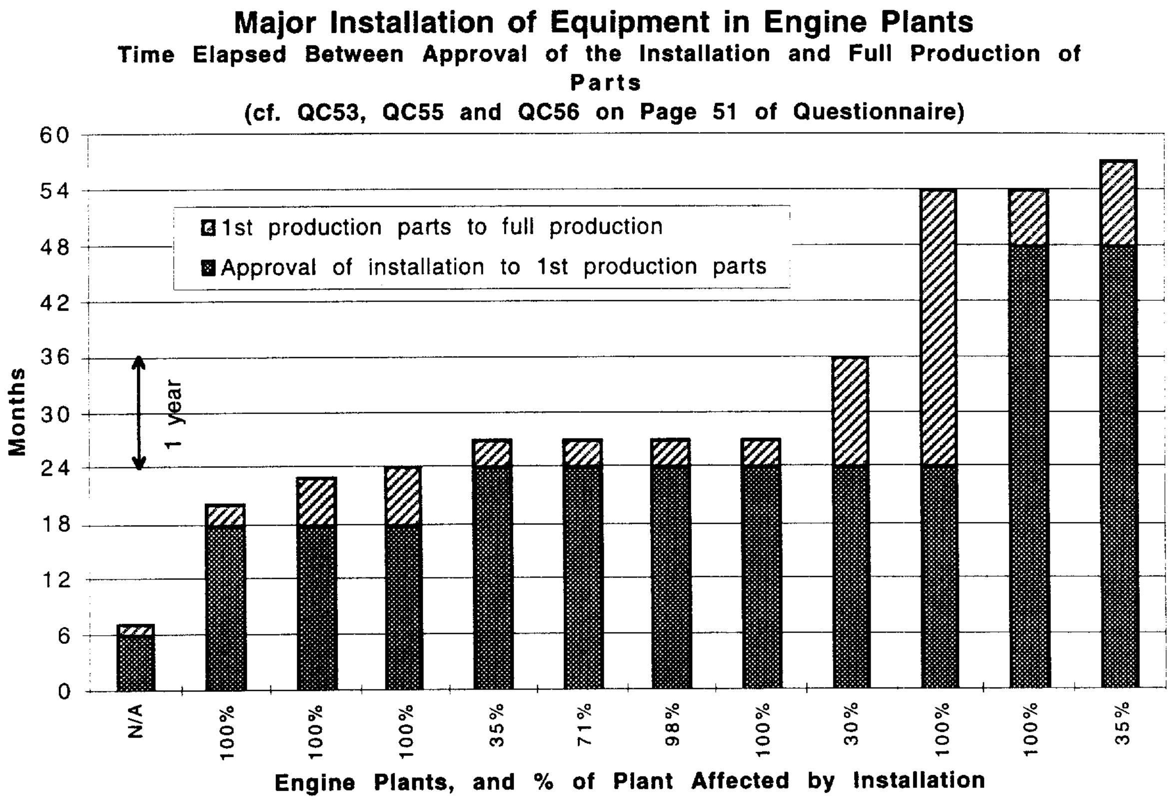


Chart 7.1

- In general, it takes around two years between the approval of the major installation plan, and the moment when the first part is produced.

- **From there on, three to six months** seems to be a common time lapse **to reach full production** with the new equipment.

- One can note that there are some cases (cf. categories with "100%" on the horizontal axis) where the whole plant was renovated (or built) and where full production happened quite rapidly (say, one year and a half) while in other cases, such important overhauls have been much more lengthy.

Engine plant performance measures

In this section, the respondents were asked to rank, by decreasing level of importance, several key ratios which are used by their company in order to monitor the performance of the engine plant. There are two categories of indicators which we asked about: financial and non-financial ratios.

Financial indicators

Table 7.1 presents the number of instances where each of the proposed financial indicators is mentioned, along with its importance in the eyes of respondents. The overwhelming **number one** indicator which is viewed as important to assess the financial performance of an engine plant is "**variance from budget**". [Note: in the IMVP Vehicle Assembly Plant Study, "variance from budget" also ranks first in importance, but along with other financial indicators as well.]

C.7.3. Engine Plant Performance Measures

Table C.31: Key Ratios -- **Top-5** ***Financial*** **Indicators** (cf. Questionnaire Page 51)

Rank in importance (1 = most important)

N.B. No re-ranking for this datasheet

	(Most	**important...)**		**(...Least**	**important)**
Rank	1	2	3	4	5
Financial indicators	(Number of instances (out of the 14 plants which answered) = number of "*")				
Cash flows			*	* * * *	
Contribution to margin		*	*		*
Cost of capital	*	* * *			* *
Economic income			*	*	*
Gross margin	*	* *			
Inventory levels	*	* * * *	* * * * *		* *
Return on sales		*		* * *	
Operating income % of sales	* *	* *			*
Return on assets	*		*		
Return on equity					
Sales or sales growth			*	*	*
Variance from budget	* * * * * * * * * *	*			
Residual income		*			

Table 7.1

It is interesting to note that several financial ratios are not used and/or not viewed as important by many of the engine plants surveyed. For instance, **return on equity and return on assets do**

not matter at all, when automakers evaluate the performance of their engine plants (nowadays). This is clearly very different from what happens in many other industries. But we ought to bear in mind that the **market for automobile engines** is still very much a **captive** one. With this in mind, we can understand that "sales or sales growth" are very insignificant factors: these numbers are directly a function of how many cars are built by the parent car firm.

Some attention is paid towards controlling capital and inventory costs. This makes sense, because engine plants (more than many other production facilities in the automotive supply chain) are places where a lot of expensive capital equipment is installed and used in order to machine, assemble and test sophisticated items like engines. Concerning inventory, we wanted to see what the inventory levels are in those plants which regard them as a crucial financial indicator. By looking at Chart 7.2, one can conclude that the **engine plants whose respondents say that controlling inventory levels is most important**, do tend to **have lower levels of inventory** currently (for this correlation, we use a normalized inventory value).

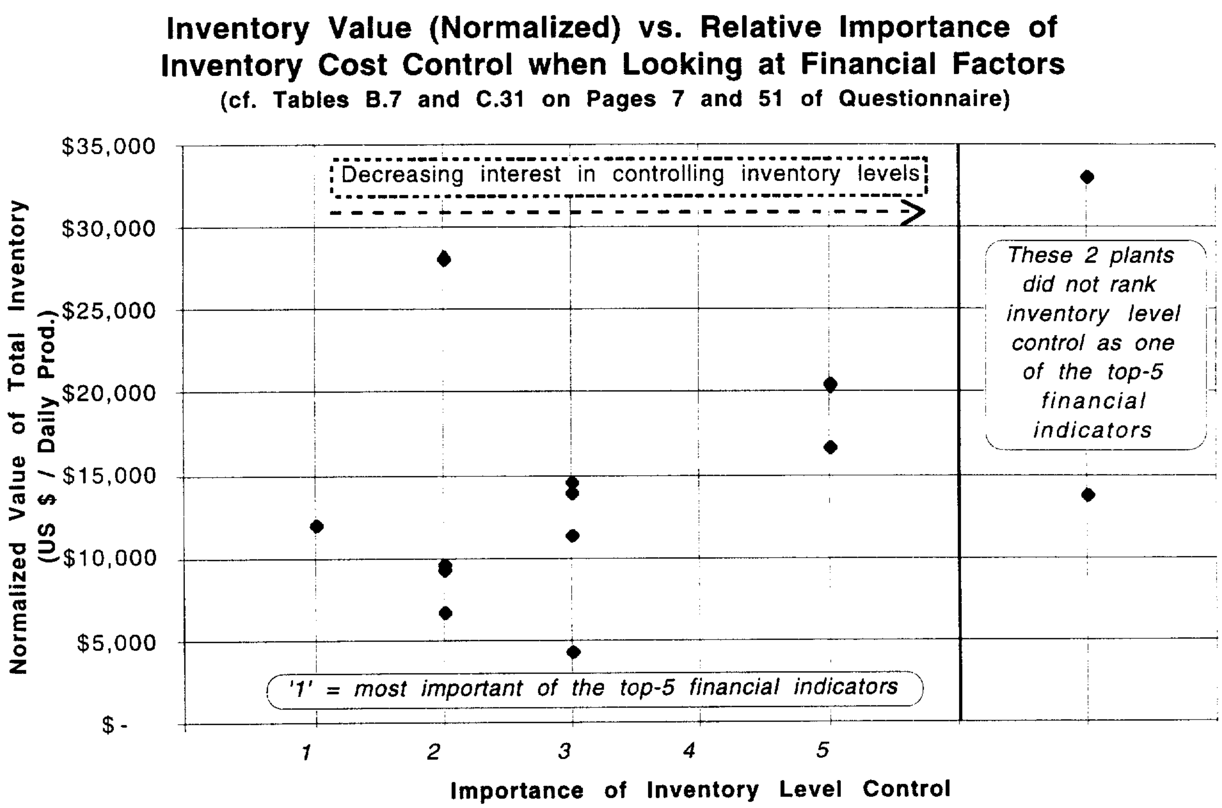


Chart 7.2

Non-financial indicators

Clearly, the **quality** of the engines produced constitutes the **top priority** for companies when they evaluate their engine plants: all respondents ranked "product quality" as one of their very most important non-financial indicators of engine plant performance. [Note: the same holds true for vehicle assembly plants, we were told by the IMVP researchers who are in charge of that study.]

C.7.3. Engine Plant Performance Measures

Table C.31: Key Ratios -- ***Non-Financial*** **Indicators** (cf. Questionnaire Page 51)

Rank in importance (1 = most important)

N.B. Re-ranking for this datasheet, so that answers span the [1-5] rank range

	(Most important...)			**(...Least**	**important)**
Rank	1	2	3	4	5
Non-financial indicators	(Number of instances (out of the 14 plants which answered) = number of '*')				
Direct labor productivity	*	* * *	*	* * *	*
Delivery performance	* * *	* *	* *	*	*
Equipment productivity		*	*	* *	* * * *
Overall labor productivity		* * *	* *	* * * *	* *
Machine uptime		* *	* * *	* *	* *
Manufacturing flexibility	*				* * * *
Market growth					
Market share					
Material yield		*	*		* * *
Product quality	* * * * * * * * * *	* * *			
Safety, environment	* * * * *	* *	*	*	*
Technological capability		*	* *		*
Schedule performance	*	* *	* * * *	*	* *

Note: two or more indicators can be given the same rank by a respondent.

Table 7.2

Overall, the next item to be listed as most important for engine plant "monitoring" covers safety- and environment-related issues (see Table 7.2). [Note: for vehicle assembly plants, safety and the environment are important too, but not as much as in the present study about engine plants.]

Attention is also quite high regarding:

* logistical issues like delivery performance and schedule performance,
* labor productivity (direct and overall).

Finally, we asked about the relative importance that is given to financial indicators (vs. non-financial ones) when firms assess their engine plants. Chart 7.3 shows that the weight of *financial* indicators varies between 10% and 60% for the 13 plants for which we have answers. About this topic, there is no striking difference in practice between plants located in North America and those from Europe.

Weight Given To Financial And Non-Financial Indicators When Assessing Engine Plants
(cf. QC57 on Page 52 of Questionnaire)

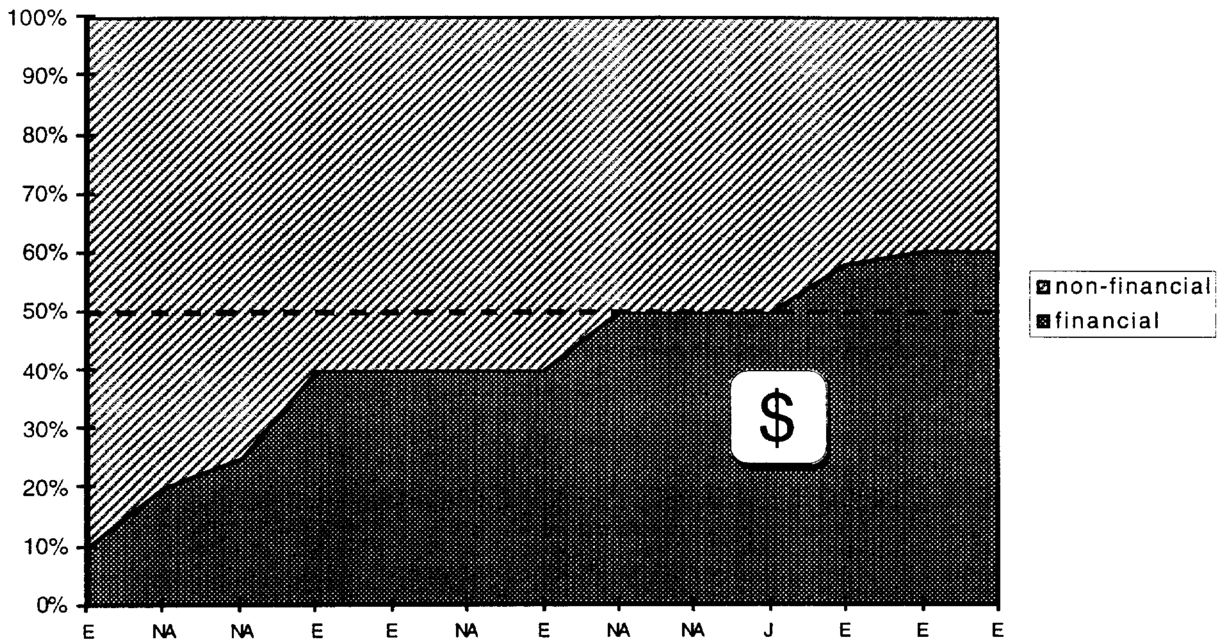


Chart 7.3

Investment decisions

Table 7.3 indicates the relative importance of several factors when investment decisions concerning engine plants are made.

C.7.4. Investment Decisions

Table C.32: Factors Involved in Investment Decisions (cf. Questionnaire Page 52)

Rank in importance (1 = most important)

	(Most important...)					(...Least important)
Rank	1	2	3	4	5	6
Factors	Number of '*' = number of instances (out of 15 engine plants which answered)					
Technological need	* * *	* * * *	* *	*	* * *	
Internal rate of return (IROR)	* * * * * * *	* *	*	*	*	
Technological opportunity		* * *	* * * *	* * * * *	*	*
Product quality	* * * * * * *	* * * *	* * * *			
Payback	* *	* *	* *	*	* * *	*
Safety/ergonomics		* * * * *	* *	* * *	* * *	

Note about IROR used by companies: answers are 15%, 30%, 35%, 40% (twice), >40%

Note about payback period used:

Number of years	1	2	3	Other	5	6
Number of answers	1	4	1	Engine 1/2 life	1	1

Table 7.3

- As a group, engine plants rank "product quality" and "internal rate of return" as the two most important factors involved in investment decisions. Then, by decreasing importance, come technological need and the other factors listed in Table C.32.

- Engine plants located in North America *all* rank "internal rate of return" as their number one or number two most important factor.

- We have also indicated what internal rates of return are commonly used by companies: it ranges from 15% to more than 40%.

- Concerning payback, a 2-year period is most commonly used, but results differ once again among the engine plants surveyed (from 1 to 6 years).

Indirect cost allocation

Table C.33 in the questionnaire deals with indirect cost allocation: while many factors were proposed in the list, in general, respondents indicated that only a few of them are in use in their company: more precisely, "**standard labor hours**" is by far the **most commonly used** method, followed by "actual labor hours", as can be concluded by Table 7.4.

C.7.5. Indirect Cost Allocation

Table C.33: Methods for Indirect Cost Allocation (cf. Questionnaire Page 52)

Question: Which of the following methods is/are used to assign indirect costs?

Frequency	**(Most frequent...)**		**(...Least frequent)**
Factors	Number of answers		
Standard labor hours	**********		
Standard labor cost	**	*	*
Actual labor hours	****	***	*
Actual labor cost		**	**
Material consumed (std. units)		*	
Standard machine hours	*	**	
Material consumed (std. cost)	*		*
Actual machine hours	*		*
Material consumed (actual cost)		***	*

Table 7.4

Activity-based costing systems

At the time when these engine plant surveys were filled out (i.e. around 1995), **only 5 out of 16 engine plants said that they used an activity-based costing (ABC) system**. Nothing specific seems to distinguish those 5 engine plants: they are located in Europe, in North America and in Japan; there are old and new plants among them. Also, we observed that an automaker might have some engine plants with ABC in place while some of its other facilities do not use an ABC system.

Activity-Based Costing

QC 58 (page 53): Is an activity-based costing (ABC) system in use in this plant?

QC 59 (page 53): If yes, what percent of cost centers are in the ABC system?

Answers given by the engine plants surveyed:

"YES"	5	(% of cost centers affected by ABC: 33%, 80%, 99%, 100%, 100%)
"NO"	8	
No Answer	3	

Table 7.5

In those plants where ABC is used, the percentage of cost centers affected was usually between 80% and 100% (except 33% in one engine plant), as shown in Table 7.5.

8. Plant improvement efforts

Table C.35 deals with plant improvement efforts: from a list of 11 items in the questionnaire, respondents from engine plants were asked to indicate how important each of them was. The items cover issues such as plant flexibility, cost improvements, different kinds of productivity, the interaction with other services within the company as well as with suppliers of components and industrial equipment.

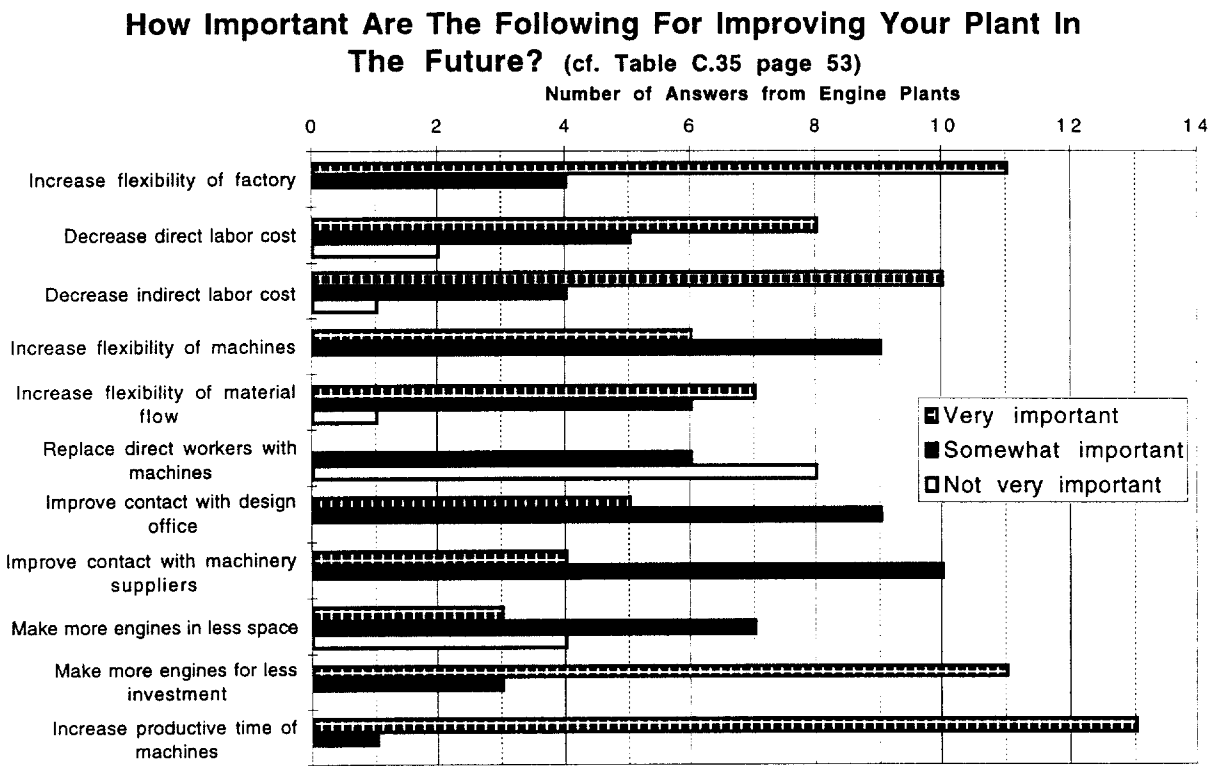


Chart 8.1

The data presented on Chart 8.1 enable to make the following conclusions:

- "Automation": for most people, the **replacement of direct workers by machines does *not* represent a top priority**. This is even the least important of the many items proposed in the table! However, it is interesting to note that labor productivity seems to be a metric which is monitored with a *great* deal of attention in the automobile industry.
- **The desire to improve flexibility of engine *factories* is very strong** (in general, it is even stronger than the desire to improve the flexibility of machines and of the material flow, which are also two priority items). Other very important items are the reduction of both direct

and indirect labor cost, along with a better usage (time-wise and money-wise) of the manufacturing equipment deployed in engine plants.

- Logically, respondents also estimate that it is fairly important to **improve** (the quality of) their **contacts** with people in the design office and with the suppliers of machinery. [Note: this desire makes a lot of sense, all the more as we have seen in Chart 5.7 that changes in engine design (which is something which affects the way they are manufactured) are very often caused by the engine design department.]

- About the desire to be able to build more engines in less space, we made an interesting finding, by comparing the answers from Table C.35 to some quantitative data about the engine plants. On Chart 8.2, we separated the group of 5 **engine plants whose respondents claim that "building more engines in less space" is "very important"**. It turns out that the plants from this group **already use less space**, compared to the average floor space utilization of our sample! It might imply that, the more efficient you (already) are at producing engines in less space, the more you realize that such an issue is crucial.

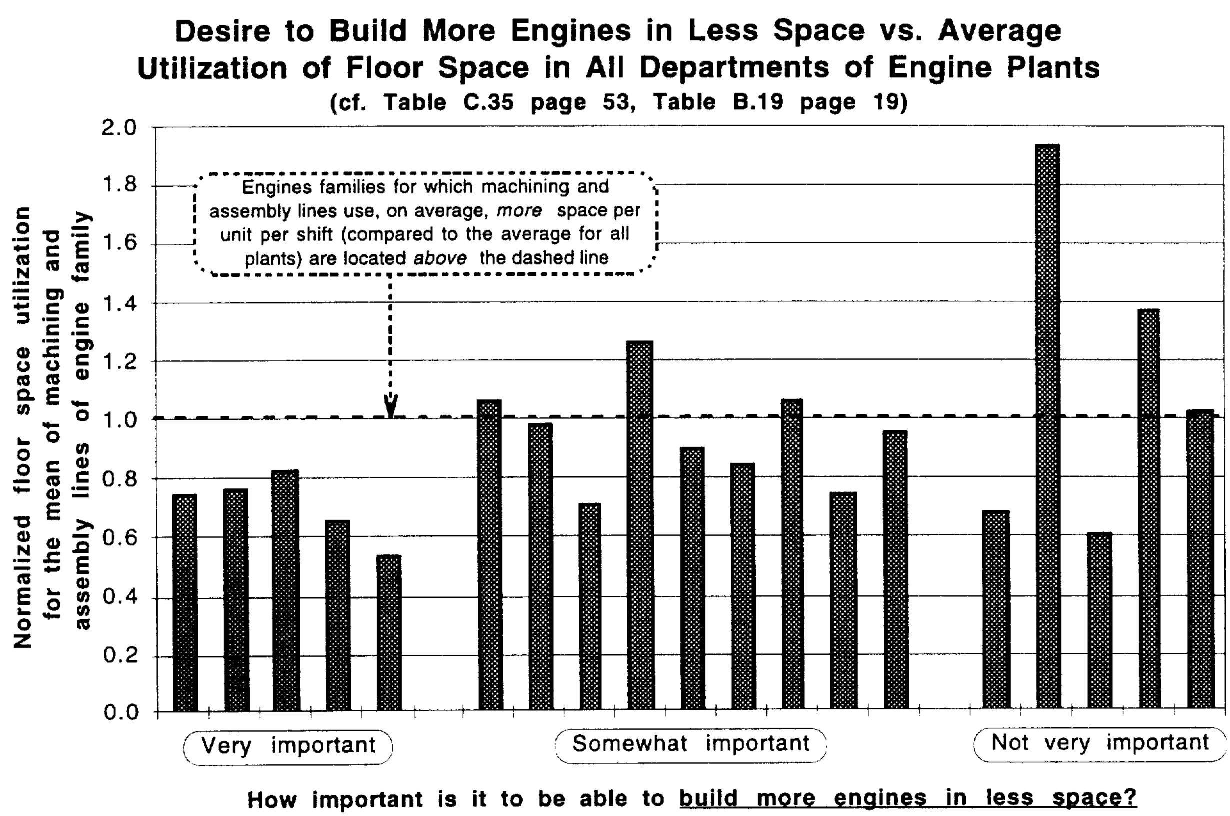


Chart 8.2

Comments on flexibility

In Table C.35 whose results we have just talked about, there are 3 types of flexibility which are mentioned: the flexibility of the factory, the flexibility of machines, and the flexibility of material flow. The respondents almost always answered that it was "very important" or "somewhat important" to improve these types of flexibility. We wanted to check if their answers depend on the level of engine variety which their plants are currently dealing with. Chart 8.3, Chart 8.4 and Chart 8.5 help tackle this issue. [Note: the variety index plotted on these graphs is identical to the one which had already been used in previous presentations: it ranges between 0 and 1, and it increases with the number of engine variants (0 means no variety at all).]

For each of the three flexibility topics, those **plants which claim that "it is *very* important to increase the flexibility"** are basically those which **currently deal with *less* engine variety** than the other plants which estimate that increasing the flexibility is "somewhat important". A reason for this might be that, in engine plants where the variety index is low, people expect and/or fear that in the future, they will certainly have to manufacture more engine variants, and therefore, they believe that it is *very* important to increase the flexibility of their operations.

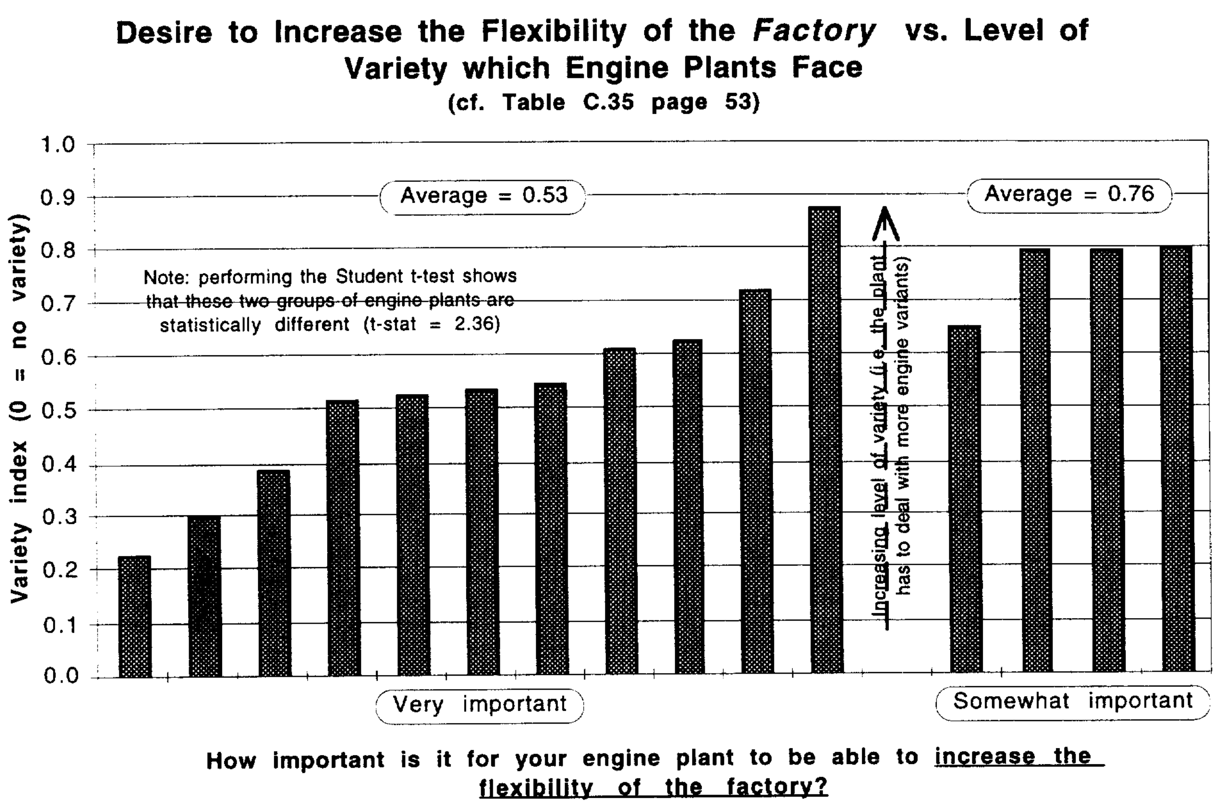
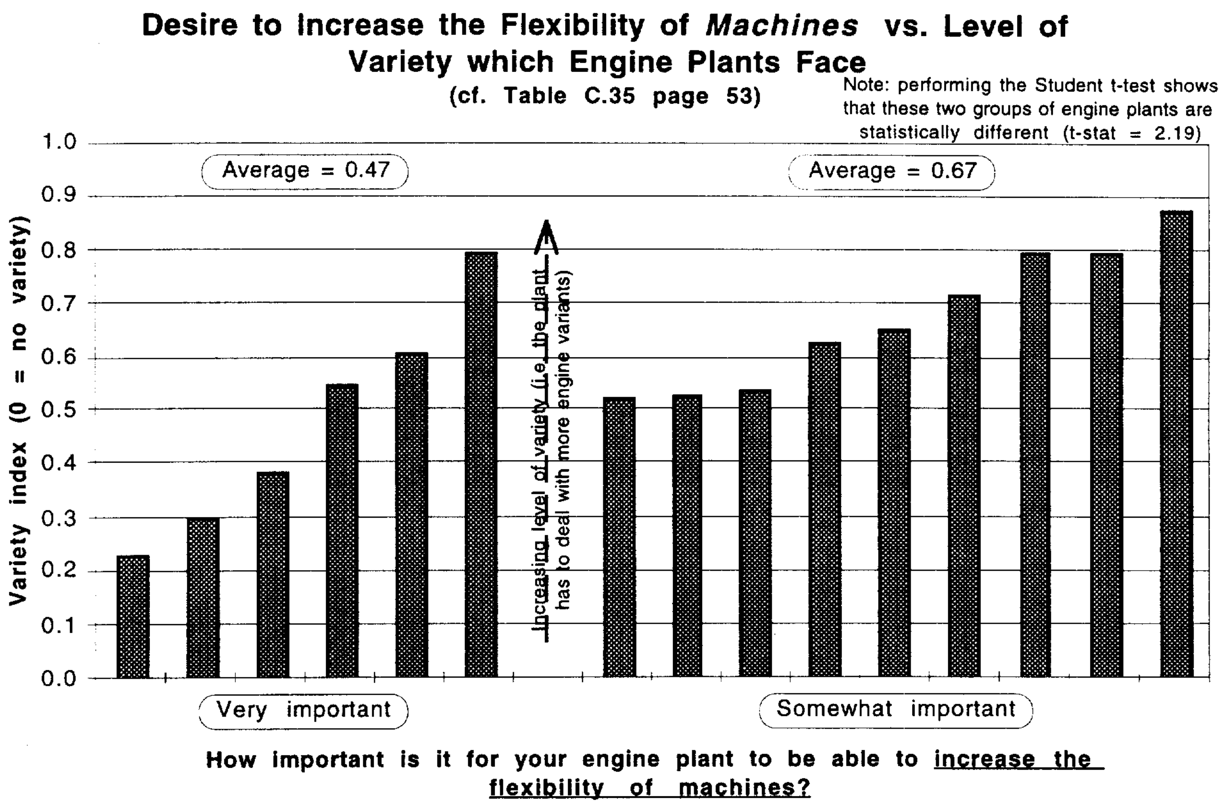


Chart 8.3



Desire to Increase the Flexibility of *Machines* vs. Level of Variety which Engine Plants Face
(cf. Table C.35 page 53)
Note: performing the Student t-test shows that these two groups of engine plants are statistically different (t-stat = 2.19)
Average = 0.47
Average = 0.67
Variety index (0 = no variety)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Increasing level of variety (i.e. the plant has to deal with more engine variants)
Very important
Somewhat important
How important is it for your engine plant to be able to increase the flexibility of machines?

Chart 8.4

Desire to Increase the Flexibility of *Material Flow* vs. Level of Variety which Engine Plants Face
(cf. Table C.35 page 53)

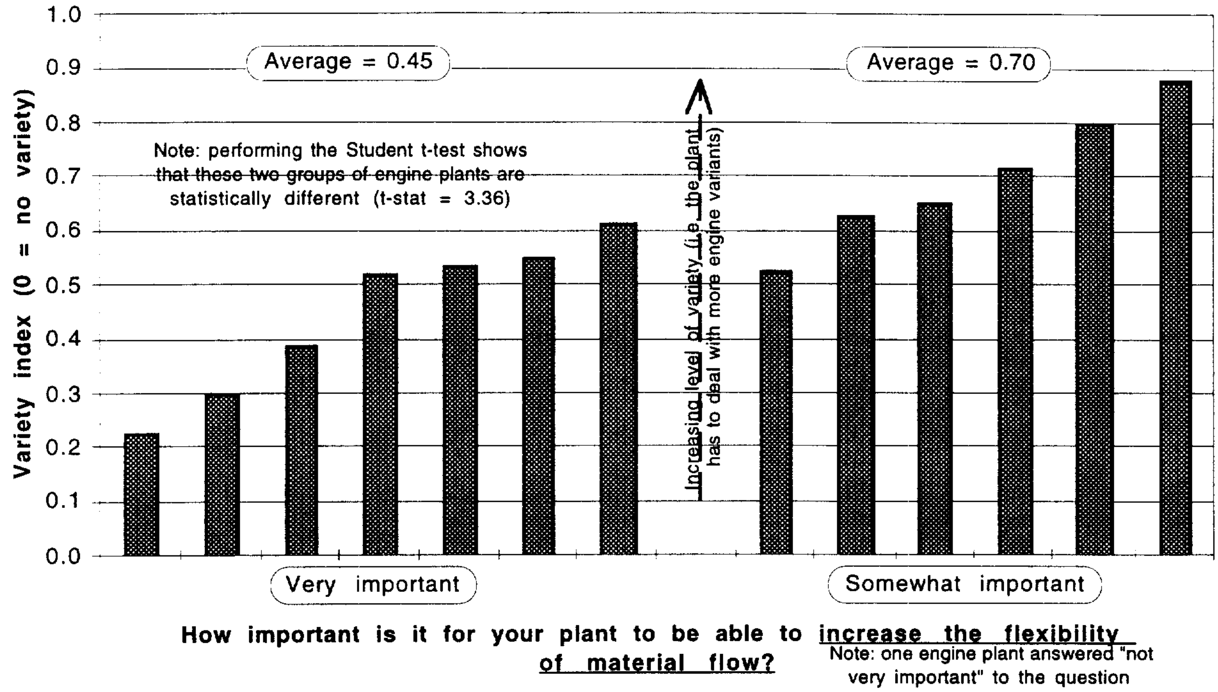


Chart 8.5

Conclusion

With this paper, we wanted to share findings about policies and procedures currently in place throughout automotive engine plants all over the world. By analyzing the results from this IMVP survey, we could see that, while some aspects of lean production have been successfully implemented in several facilities (e.g. more training goes along with a higher rate of suggestions by workers), in many aspects of this comparative study (such as logistics, maintenance, and accounting procedures), the industrial environment in which *engine* plants operate makes them less exposed to some of the pressures that have forced *automobile* assembly plants to increasingly adopt the lean production paradigm.

Some specific characteristics of automotive engine plants ought to be kept in mind, namely:

- Engine plants are very capital-intensive facilities.
- Engines can be produced there for very long periods of time with only small, incremental modifications (although the life span of engine families is shrinking, it is still much longer than the life span of cars).
- The engine components for which the pace of technological evolution is fastest are not actually *made* at the engine plants; rather, they are often outsourced.
- Automotive engine plants almost always operate in a captive market situation, and they are placed one step behind vehicle assembly plants in terms of feeling the competitive pressure from other automakers.

Following are selected striking observations which can be made in conclusion of this paper. On the one hand, we have seen the following: (i) there is a big difference between Japanese and Western firms in terms of how frequently engine parts are delivered to the *assembly* departments of engine plants; (ii) maintenance programs like TPM have only been in place for a few years; (iii) a major installation of equipment often takes more than two years to be implemented; (iv) sales growth, return on assets or on equity do not count at all as important financial indicators used by car companies to evaluate the performance of their engine plants. These examples illustrate how difficult it is for lean principles to diffuse throughout many engine plants of automobile manufacturers. On the other hand, there are some signs showing that people within engine plants recognize the need for their whole organization to become leaner, by better utilizing resources (in terms of equipment, space) and by continuing to empower workers; moreover, top-priority items for automotive engine plants are increased flexibility and strengthened communication links with other departments involved in engine design and manufacturing.