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How to Arrive at Computer Integrated Manufacturing: A 3-year Survey

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How to Arrive at Computer Integrated Manufacturing: A 3-year Survey

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Abstract: The large majority of modem production companies have at their disposal a multitude of computer systems. The immediate challenge for these companies consists of integrating these computer systems and databases. How will one arrive at this integration? On the basis of a questionnaire administered in 1985, 1986 and 1987 among a group of large European manufacturers, one comes to the conclusion that this integration is one of the immediate priorities for this group of companies. They do not intend to implement turnkey systems, but instead will integrate the different databases and computer systems gradually. One can see emerging islands of integration, which will be connected later on through the materials requirements planning function. This has, of course, important consequences for the management of the company's information function and the market position of software suppliers.

Keywords: Information systems, integration, manufacturing

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1. Introduction

Many manufacturing companies, in both assembly and process industries have initiated significant efforts to create the factory of the future or the computer integrated factory. Part of these efforts consists of integration of the existing manufacturing information systems and the creation of new systems and databases which fit the existing framework.

Indeed, most of these manufacturing companies are no newcomers with respect to computerized information systems. With a few exceptions, they have many systems, consisting of different hardware and innumerable software applications, which can be separated into three categories. There is first the category which can be labelled “Manufacturing Automation”. This category incorporates NC machines, computer aided inspection, automated materials handling, and warehouses and flexible machine systems. The second category, labelled “Manufacturing Planning and Control System”, consists of master production scheduling, aggregate capacity planning, shop floor control, etc. The third category groups together the applications in design, drafting, process planning, engineering, etc. and can be labelled “Computer-aided design and engineering”.

Most of the application software has been developed independently and is often processed on machines which are usually at best able to communicate with each other, without being able to work together, to share common databases, or to collaborate.

In recent years, one can see increasing attention being paid to the integration of this variety of information systems. Several factors drive this evolution. The market is definitely one of them. In a wide range of sectors of industry, the customer requires a higher variation of specifications, and a faster and more accurate delivery time and quality. This puts a demand on the manufacturing function to respond faster to engineering changes, to change processes more often, to deliver faster to the customer, and to be able to adapt to changing volume requirements. In other words, the markets require producers to become more flexible. This flexibility has, however, to be realised without giving up on cost efficiency [5]. One of the ways to arrive at such a cost-efficient flexibility is the fast exchange of data and the common interpretation of data by engineering, production and sales. If engineering and manufacturing work on the same database, and this can lead to a faster update of bills of materials or process descriptions, or if this can lead to engineering preferably making use of already available components, then the introduction of new products can be speeded up. If sales data, confirmed orders or forecasts and distribution information are available to the production planning on a real time basis, and in a form amenable for immediate processing for the production department, the production planning can probably become more responsive to the market.

Apart from this 'external' reason, there exists equally 'internal' forces which stimulate integration. Over the last decade we have seen a major shift in the structure of manufacturing costs. The proportion of direct labour costs to total manufacturing costs has been decreasing gradually, compared with other elements of manufacturing cost, such as energy, raw materials, components and manufacturing overheads. In a recent study [4,5,6], it was found that for a sample of large manufacturing companies in Japan, North America and Europe, the proportion of direct labour costs is on average less than 15% of the total manufacturing cost. As a consequence, cost savings in the direct labour force tend not to be easy to obtain, whereas more effective cost saving programmes often assert economic use of materials or a higher exploitation of capital equipment and management systems. Here again, reviews of literature [1] on the use of CIM systems indicate that these systems can contribute to time saving in product development and production cycles, reduced consumption of raw materials, lower work-in-progress and finished goods inventory, less scrap and rework, higher quality and, generally speaking, increased productivity.

The challenge to management contained in the use of CIM systems is often less in the design of the system than in its implementation [7, 10]. Tools and machines are in use or can be modified, but the real challenge is the implementation of an integrated system of centralised and decentralized databases and communication links which will enhance a company's attempts to protect and strengthen its competitive position. In this paper, we will try to provide insight into how the integration of information systems is implemented.

2. The research question

Several options are available. Some vendors propose completely integrated turn-key installations. However, rarely will one find sites where such a stepwise change in the information systems can be implemented without abortive hiccups. In most of the cases, one will opt rather for an incremental approach whereby the information systems get gradually integrated.

If systems integration does not occur overnight, what path will large manufacturers take to reach CIM? Is it a hub and spoke approach whereby newly designed databases will be linking different systems? Is it a network whereby every system will be linked with every other system? Will central databases coexist with decentralised databases? In other words, what will be the architecture of the information network?

To answer these questions, different stances can be taken. One can take a modelling point of view and try to design an optimal system given the technical constraints and the strategic needs of the company. Or, one can try to discover how companies are actually building up and integrating systems. It is precisely this approach (i.e. the description of the integration as it happens in the field) which will be developed in this paper.

3. Methodology and sample description

The empirical results, examined here, are based on the data of the European Manufacturing Futures Survey. Since 1983, INSEAD has administered a survey of large European manufacturers with the aim of providing a description of current thinking on manufacturing strategy in large manufacturing units in Europe.

Each year, the questionnaire was sent to about 1500 companies in Europe. The respondents represent companies from all EEC countries, except Greece, Luxembourg and Portugal but complemented by Australia, Finland, Norway, Sweden and Switzerland. The sample is definitely not representative of European industry. The composition of the sample is such, however, that there is no bias towards a particular industry of any European country. Except for the production of electronic and electrical equipment, which accounts for about 20% of the sample, none of the industries (based on a two digit SI code) represent more than one sixth of the sample. Given the limited response rate, one could argue that those who answered are companies where manufacturing strategy is an important subject. This has, however, limited impact on the results in this paper. Indeed, companies which have a high interest in manufacturing strategy are not necessarily the same as those companies which invest heavily in computer systems and databases. In our opinion, the sample is not biased towards this last group of companies.

In the 1983 and 1984 campaign, it became apparent that integration of information systems seemed to be an important action plan for our respondents. Out of a list of about 40 potential action plans, the integration of information systems in manufacturing and across functions proved always to be in the top ten of action plans in which the respondents intended to invest over the two years following the year for which the questionnaire was filled out. Intrigued by this consistent attention paid to integration, the researchers decided to add a few questions which could clarify what the respondents meant by this integration. For a selected list of 12 computerised subsystems and databases, the respondents were asked:

(i) to indicate on a Likert scale to what extent these information systems are computerised (the scale ranged from not at all through to a fully computerised system);

(ii) to indicate on a 12 by 12 triangular matrix which pairs of computerised subsystems or databases they intended to integrate over the next two years.

The 12 computerised subsystems, which were submitted to the respondents are

(1) Sales planning and forecasting.
(2) Inventory status.
(3) Master production scheduling.
(4) Shop floor control.
(5) Design engineering (including computer aided design (CAD)).
(6) Manufacturing engineering (including computer aided manufacturing (CAM)).
(7) Process controls.
(8) Quality reporting.
(9) Accounting.
(10) Order entry.
(11) Purchasing.
(12) Distribution.

We hold no claim that the list is exhaustive. It is the result of a trade-off between selecting a broad band of the computerised subsystems and data-bases in manufacturing, and limiting it to a list which could be overlooked by the respondents.[1]

In Table 1, one can find the number of respondents for each of the years for which the data is available and the number of respondents which answered the questions.

Table 1: Sample description

Year	Number of respondents	Number of respondents answering the questions related to integration of information systems
1985	173	144
1986	174	151
1987	223	200

4. Results

Is integration of information systems an intensive exercise? To have a first impression of that, one can look at the number of pairs which are ticked off by each of the respondents. It appears that in each of the years the respondents intended to invest efforts in a selection of 9 pairs on the average (see Table 2). A yardstick to measure whether this is high or low does not exist. We tend to consider this rather low to average, if we keep in mind that integration of information systems is a major priority for the group of respondents.

[1] For the results in 1985, refer to [3].

Table 2: Numbers of pairs chosen for integration

	1985	1986	1987
Median	7.0	6.0	6.0
Mean	9.7	8.3	9.4
(No significant statistical differences between the years)			

Before focusing on the nature of the integration of information subsystems, one has to address the question: which subsystems or databases are already computerised? Indeed, this study provides a picture of the use of information systems and the intention to integrate at a particular moment, i.e. the period 1985-1987. All of our respondents have computers at their disposal, and all of them have computerised subsystems and databases.

Table 3 lists the degree of computerisation of the databases and subsystems in 1987. There is no substantive difference between the degree of computerization of each of the selected computer systems over the period of two years for which we have data at our disposal. This indicates perhaps that the effort in computerisation is not any more directed at the computerisation of stand alone systems, but that integration is really the key issue in the investments in computer systems. The subsystems or databases are rearranged in descending order of computerisation. They are divided into five groups. The rank orders of the items within the groups are not significantly different from each other (on a 1% significance level (two-tailed)) based on a Wilcoxon matched-pairs signed-ranks test. The difference between the groups is significant on the basis of this non-parametric test.

Table 3: Degree of computerisation in 1987 (in descending order and grouped on the basis of a Wilcoxon matched-pair signed-rank test ($p < 0.1$) (scale from 1 to 7)

Information system	Mean	Median	Mode
1. Accounting	6.0	6	6
2. Order entry	5.5	6	7
Inventory status	5.3	6	6
3. Purchasing	4.8	5	6
Master production schedule	4.6	5	6
Distribution	4.4	5	5
4. Sales planning	4.1	5	5
Shop floor control	4.0	4	5
Process controls	3.8	4	5
5. Quality reporting	3.6	4	3
Design engineering (incl. CAD)	3.3	3	2
Manufacturing engineering (incl. CAM)	3.1	3	2

Accounting is the most computerised sub-system. Inventory status and order entry rank second. MPS and MRP, purchasing and distribution form a third group in the order of importance. Sales planning, shop floor control, process controls and quality reporting are at the same level of computerisation and fourth in rank. The bottom group consists of design engineering and manufacturing engineering. They are, in half of the cases, slightly or not at all computerised. The groups themselves have face validity. Inventory status and order entry are logically linked. Order acceptance is indeed often dependent on the inventory status of either finished goods or raw materials and work-in-process.

Purchasing, MPS and distribution belong to the same group of production planning programmes. Shop floor control, process controls and quality reporting on the one hand, sales planning and forecasting on the other, are the more technical and operations aspects of production and sales. Manufacturing engineering (including CAM) and design engineering (including CAD) are more technologically orientated systems and have become only in the last decade available to a broader range of manufacturers. One could argue that the extent of computerisation reflects the history of the introduction of computer support information and decision support systems in the industrial world.

Having said this, what are the future plans of the large European manufacturers, concerning the integration of these databases and subsystems? To this aim, the respondents were presented with an upper triangular matrix in which the twelve systems or databases were combined with each other. This leads to 66 possibilities of integration. The respondents were asked to indicate those pairs they intend integrating more fully over the next two years. The advantage of using this time frame is that the respondents can state what may be achieved rather than declare an ideal configuration which might be to integrate all subsystems: they have to focus on the major integration plans for the immediate future.

Table 4 represents the number of respondents who ticked the boxes during the 1987 survey. In Table 5, the ten most often ticked pairs are shown.

Table 4: Frequency with which pairs were ticked off for intended integration (n = 200) (1987)

	2	3	4	5	6	7	8	9	10	11	12
1. Sales planning (359) [a]	61	85	13	10	9	10	14	25	54	36	42
2. Inventory status (405)		80	43	7	9	15	20	47	33	59	31
3. Master production schedule (489)			55	17	32	35	29	27	39	54	36
4. Shop floor control (312)				16	27	48	41	25	14	18	12
5. Design engineering (155)					55	20	15	3	4	6	2
6. Manufacturing engineering (252)						51	38	8	6	10	7
7. Process controls (305)							80	20	7	11	8
8. Quality reporting (330)								32	11	33	17
9. Accounting (294)									33	49	25
10. Order entry (279)										34	44
11. Purchasing (333)											23
12. Distribution (247)											

[a] Numbers between brackets indicate the total number of times a system was mentioned in conjunction with another one.

Table 5: The ten most frequently matched pairs of databases for further integration [a]

1 Sales planning-Master production schedule	(85)
2 Process controls-Quality reporting	(80)
3 Inventory status-Master production schedule	(80)
4 Inventory status-Sales planning	(61)
5 Purchasing-Inventory status	(59)
6 Shop floor control-Master production schedule	(55)
7 Design engineering-Manufacturing engineering	(55)
8 Order entry-Sales planning	(54)
9 Process controls-Manufacturing engineering	(51)
10 Purchasing-Accounting	(49)

[a] Numbers in brackets show the frequency for each matched pair

The tables allow us to highlight a few preliminary results:

(a) The master production schedule and inventory control are clearly a core database/information system in the efforts toward integration. In the top ten list, they are both mentioned three times in conjunction with other systems. This is confirmed by examining the number of times these information systems are mentioned in conjunction with others. The master production schedule is mentioned a total of 489 times in conjunction with other systems, while inventory status is mentioned 405 times.

(b) There seems to exist a clear cut between more administration oriented systems, such as inventory control, MPS, etc. as opposed to more technically oriented systems such as design and manufacturing engineering, process controls, etc. The only link between those two groups is the link between shop floor control and master production schedule.

(c) Accounting, the most computerised information system is mentioned only once in this top ten list, and this in conjunction with purchasing. This can indicate two possibilities: either accounting is already integrated up to a satisfactory level, or the respondents do not feel the need to integrate this highly computerised information system. This last interpretation would in fact corroborate some recent studies [8] which suggest that today's accounting systems are not adapted to the needs of today's manufacturing. Perhaps senior manufacturing managers do not want to push for integration, fearing that they would integrate obsolete systems, and might prefer to wait until accounting has updated its approaches.

(d) Design engineering, low on the list of computerisation, is also the information system which is least often mentioned in conjunction with others. If it were not for the (even for laymen) popular CAD/CAM link, which is mentioned 55 times, design engineering would remain a very isolated information system. Two types of hypothesis can be formulated with respect to this isolation. First, the low degree of computerisation makes integration of course more difficult, though not less necessary.

Secondly, the integration between design engineering and manufacturing information systems requires not only technical barriers to be overcome, but it also needs the reduction of organisational barriers. The organisational problems related to the integration of sales, manufacturing and design may still be too large to push hard for a short term (2 years) integration of databases and information systems.

How did the intention to integrate change over the last three years? Comparing similar tables to Tables 4 and 5 for 1985 and 1986 does not allow us to find many differences. On a basis of a paired t-test between the answers of those senior manufacturing managers which replied in 1985, as well as in 1986 and 1987, one can see the statistically significant differences (on a 5% two-tailed confidence level) in Table 6.

Table 6: Changes in intention to integrate

	Decrease in effort	Increase in effort
From 1985-1986 (41 answers)	Design engineering-Accounting	
		Accounting-Purchasing
From 1985-1987 (45 answers)	Sales planning-Inventory control	Inventory control-Shop floor control
	Shop floor control-Manufacturing engineering	Quality reporting-Accounting
From 1986-1987 (41 answers)		Inventory control-Accounting

The only striking differences are perhaps:

(1) a gradual decrease in emphasis of integration of shop floor control with the more technically oriented systems, and

(2) an integration of accounting with quality reporting and inventory control.

Especially this last trend might indicate a real change. After a lot of negative comments on the incapabilities of accounting systems to cope with new manufacturing programmes concerning zero defects and just-in-time production methods, the attempt to integrate accounting more effectively might indicate that accounting methods are adapting, and that manufacturing is trying to use accounting data to justify new manufacturing methods. One has to be extremely careful with this conclusion, since we see only a very small change from one year to another.

5. A different type of analysis

The upper triangular matrix in Table 4 is a precise representation of the results of the survey, but it may be difficult to interpret. To improve our understanding of the implicit models and relations from which the respondent derive their perception, we decided to use a non-metric multidimensional scaling method to present the data. The matrix indicates what respondents propose in attempting to bring pairs of databases or subsystems together. One can see this as a measure of closeness or similarity of the databases. On the basis of this assumption a similar analysis was used to map the data.

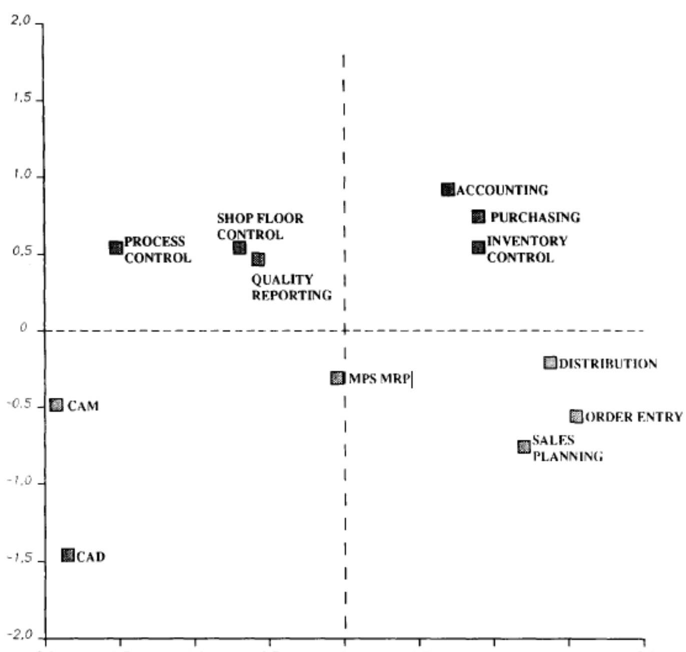
The 1987 data can be represented in a two-dimensional space, leaving a stress of 16.0% and in a three-dimensional space leaving a stress of 7.8%. According to Kruskal [9], these stress values can be considered as respectively 'fair' and 'good'. The first two dimensions of the three dimensional map are to a large extent the same as the ones in the two dimensional map. Since this map is used here for representation, only the two dimensional map will be represented. The first (horizontal) dimension contrasts the group of technical databases and subsystems, such as CAD, CAM, quality reporting process controls and shop floor control with more administrative oriented systems such as purchasing, distribution, accounting, inventory status and MPS. This is a contrast which is hinted at above. The second (vertical) dimension contrasts internally oriented information systems, such as shop floor control, inventory status, purchasing, quality reporting and process controls with systems that are oriented to groups external to manufacturing (i.e. distribution, sales planning, design engineering and order entry).

By interpreting Figure 1, one can see the results in four clusters for intended integration:

(1) the internally oriented administrative systems, e.g. inventory status, accounting and purchasing,
(2) the market oriented administrative systems, e.g. distribution, order entry, sales planning and forecasting,
(3) the internally oriented technical control systems, e.g. process control, quality reporting and shop floor control, and
(4) the technical systems, which link manufacturing to external groups such as design, engineering and eventually the customer i.e. CAD and CAM.

These four clusters have face validity and can be said broadly speaking to represent different functions within the enterprise. The first of these can in a limited sense be identified with the materials planning function, the second with the sales administration, the third with the production planning function and the fourth reflects the engineering function. Each of these signify existing functions but more importantly extend beyond their exact functions and to a lesser or greater extent integrate the other functions.

Figure 1: Integration of information systems in manufacturing



These ‘islands of integration’ seem to be linked with each other through the pivotal database which is the MPS/MRP.

This again has face validity. The use of the MPS as a linking pin is what vendors of MRP II packages often use while describing the advantages of their system.

6. Discussion and conclusions

We are, of course, very much aware that the results reported here in the paper are purely descriptive and have no normative value. They moreover do not show the static picture, i.e. what is integrated today? The data illustrates the dynamic picture of what the existing trend in integration is today.

We would like to organise our results under five hypotheses:

(a) The integration of information systems, though important in the mind of the respondents, is not characterised by a massive effort. Less than ten pairs out of sixty-six are on the average mentioned as candidates for integration.

(b) European manufacturers have opted for the creation of a number of islands of integration in their evolution towards a completely integrated manufacturing information system. The way we labelled these islands under Section 5 is, of course, purely judgmental and subjective.

(c) These islands of integration might be linked with each other through the existing database built around the master production schedule.

(d) The present degree of computerisation is not necessarily the key to explain the trend towards integration. Design engineering as well as accounting, which are at the two extremes on the scale of degree of computerisation are both not up for strong integration.

(e) Integration of information systems moves slower in Europe than one would probably hope for. When one compares the 1985 with the 1987 data, which cover precisely the two-year interval which is mentioned in the question, the differences are rather small and almost negligible. There is no significant change in the number of candidates for integration, and there are only a few slight changes mainly related to shop floor control and accounting.

How shall one interpret these results? Large European manufacturers seem to apply an incremental approach along a path which is one of 'least resistance'. Indeed, integration seems to be carried out in the first instance within the existing function of shop floor operation, delivery, sales and marketing, and design. The average European manufacturer does not seem to be prepared to get the organisational barriers down and to integrate across the existing functions. This will, however, be necessary if one wants to use these integrated information systems to pursue a strategy based on flexibility. The 'least resistance' is also indicated by the choice of the pivotal link between the different islands of integration. The respondents have chosen the master production schedule for this role. There are, of course, good reasons to do so. The master production schedule is preeminently an integrating exercise between production and sales, and consequently a natural tool to unify information systems. Moreover, the proponents of MRP II packages and methods claim that they provide to a large extent the required integration. But the third reason could be that in most companies the MPS database is the only one which has a high degree of accuracy, and for which there exists a great discipline to update and improve the date. As a consequence, it seems to be natural to hook up the other systems to this 'primus inter pares' database. One has to wonder, however, whether this is always the best strategy. Do all flexibility-driven strategies have to be built on an MRP-type of database?

The results also provide some guidance for software suppliers. If the pivotal role of MRP proves to be correct, these vendors who have built up a strong position with a flexible MRP package, seem to be at an advantage. Indeed, they will be able to force, at least partially, their standards onto suppliers of the more peripheral elements of the CIM system. Here our concern is not about technical communication standards. The standards considered are about data definition and database structure. Those vendors who start from a strong position in robotics, process control or accounting, and who have considered MRP to be a marginal product to their business, might discover that they have positioned themselves less favourably in the market for integrated manufacturing systems. This becomes even more true if there is no relation between the present degree of computerisation and integration policy. Lastly, we want to stress the positive evolution about the position of accounting in the picture of integration of information systems. If the first indication provided by the comparison of the 1985 with the 1987 picture will be confirmed, it will mean that accounting systems will get closer to quality management and modern methods of inventory control based on JIT systems.

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