An Inter-industrial Comparison Study on the Benefits of Production Information Systems

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Abstract

We exercised a cross comparison analysis on the linkage among computer-based information technologies utilized for production activities, perceived benefits of production information systems, and competitive performance of each plant, using the database for 164 manufacturing plants located in five industrialized nations from three industries (machinery, electrical & electronics and automobile), which had been established through an international collaboration on high performance manufacturing research. Information technologies we took up for the analysis include CAD, CAE, CAPP, LAN, FMS, automated retrieval and storage, MRP, simulation tools, SPC software, database for quality information, and EDI linkages among others. The benefits of production information systems were measured in terms of manufacturing cost reduction, quality improvement, lead time reduction, increase in flexibility to changing product mix and production volume, and new product introduction time reduction. We found that there are remarkable differences in the linkage structure among industries.

Keywords: production information systems, information technology, empirical research

1. Introduction

Most of the critical information flowing within manufacturing plants has been quantitative: production volume, manufacturing cost, inventory turnover, percent defective, for example. Under the name of factory automation, numerical control techniques and computers were introduced into manufacturing plants very early compared to other places in business enterprises, and production information systems have been implemented to support solving well-structured decision problems. There are numerous computer-based information technologies (ITs) or information system (IS) modules that have been used in the production function. They are computer aided design (CAD), computer aided engineering (CAE), computer aided processes planning (CAPP), numerically controlled (NC) machine tools or computer aided manufacturing (CAM), flexible manufacturing systems (FMS), automated retrieval/storage, closed-loop material requirements planning (MRP II), statistical process control (SPC) software, to cite a few. More general are local area networks (LAN), electronic data interchange (EDI) and databases. These hardware and software have constituted main modules of primary production information systems such as production planning and control system, quality management system, procurement management/inventory control system, cost management system, new product development support system, and so on. Hammer and Champy (1993) picked up famous examples of business process reengineering from Ford's parts acquisition process and Kodak's new product development process. From a strategic perspective, information technologies are often seen as a source of the core competence suggested by Hamel and Prahalad (1994).

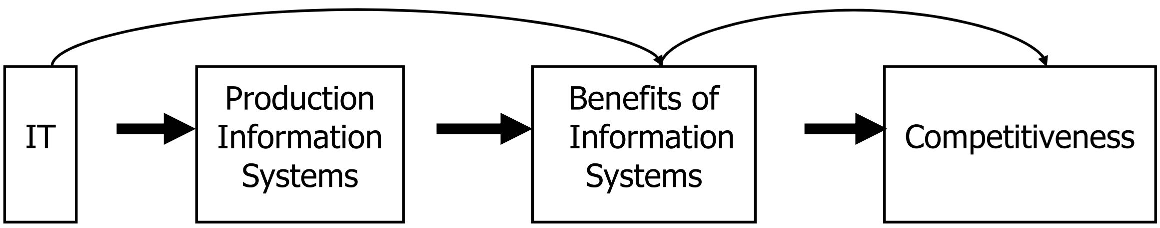
The possible benefits of those ITs have been examined in light of the objectives of the primary production information systems. For example, CAD, which is an essential module of product development systems, is supposed to have a significant impact upon reducing the new product introduction time; CAE seems to improve the reliability of parts and finished goods as a part of production engineering systems as well as hasten the new product development process as a part of product development systems; CAPP has a main effect on the reduction in cycle time; and the effect of LAN could be widespread from the automatic control of machine tools and robotics through various flows of production information. On the other hand, each benefit of the aggregate production information systems based on computers and networks can be regarded as a composite of the effects generated from every IT or information systems module implemented. Reduction in manufacturing cost could be attained through the introduction of NC machine tools, FMS, JIT software, simulation tools, computer-based production equipment control, etc. In general, certain IT has multiple benefits and certain benefit of the aggregate production information systems has multiple sources. Furthermore, the benefits of the production information systems should contribute to the competitive advantage of the manufacturing plant in some fashion.

The objective of this paper is to empirically examine the relationships among IT utilization, benefits of the aggregate production information systems and competitive performance by applying correlation and regression analyses to the plant survey data mentioned below. A primary concern is whether those ITs utilized in the production function have ever produced the beneficial effects as had been expected and have contributed to the competitive advantage of each plant. As Matsui and Sato (2000) have made an international comparison concerning those relationships, in this paper we focus on making an inter-industrial comparison of the effects of ITs on the production information systems and competitive performance.

2. Analytical Framework and Hypotheses

To assess the real contribution of ITs and IS modules to competitive performance of manufacturing plants, we establish a simple analytical framework with four major characters; information technologies, production information systems, benefits of information systems, and competitiveness. The relationships among those characters are depicted in Figure 1. Information technology

[Figure 1] Analytical Framework for Production Information Systems



CAD	Inventory management	Manufacturing Cost	Manufacturing cost
CAE	Production planning	reduction	Conformance quality
CAPP	Process design	Improved product quality	Product capability
CNC/DNC	Cost management	Lead time reduction	Fast delivery
FMS	Quality management	Increased flexibility	Flexibility to change
MRP II	New product	Reduced new product	Speed of new product
EDI	development	introduction time	introduction
etc.	etc.	etc.	etc.

ITs and IS modules for the production purpose are incorporated into production information systems, and play drivers to promote the objectives of the information systems. If the objectives are attained by the implementation of ITs, the plant can enjoy the competitive position in the global marketplace. For example, MRP II, simulation tools, and JIT software are often regarded as key parts for inventory management, whose objectives are to reduce inventory and manufacturing cost and to smooth the flow of materials and the delivery to customers. When those objectives are met by those ITs, the plant becomes globally competitive in cost and delivery dimensions.

In this research we do not explore the complicated relationships between ITs and production information systems and between production information systems and their benefits one by one. Instead, we bypass the path from ITs directly to the benefits of the aggregate production information systems. As shown in the next section, this paper deals with fifteen Information technology variables concerning CAD, CAE, CAPP, NC machine tools, FMS, computer-based production equipment control, automated retrieval/storage, MRP II, simulation tools, SPC software, database for quality information, LAN, and EDI. For both benefits of the production information systems and competitive performance indexes, we pick up six variables, corresponding to basic objectives in production operations; manufacturing cost, product quality, quick delivery, and flexibility (product-mix, production volume, and new product development).

Then, we propose the hypotheses on the relationship between implementation of ITs and benefits of the production information systems as follows:

(B1) CNC/DNC, FMS, MRP II, and computer-based production equipment control reduce manufacturing cost.

(B2) CAE, CNC/DNC, FMS, SPC software and database for quality information improve product quality.

(B3) CAPP, LAN, FMS, automated retrieval/storage, computer-based production equipment control and EDI reduce overall lead time.

(B4) FMS, automated retrieval/storage, MRP II and computer-based production equipment control increase product-mix flexibility.

(B5) Computer-based production equipment control increases production-volume flexibility.

(B6) CAD and CAE reduce new product introduction time.

(BC) There are no differences among industries in the above hypotheses (B1) to (B6).

The last one represents a complex null hypothesis concerning the inter-industrial comparison of the IT effects, which can be broken down into six individual ones. We intended to hypothesize that there should be some differences among industries in spite of the universal nature of ITs.

Figure 2 illustrates the hypothesized effects of ITs on the aggregate production information systems, (B1) to (B6), as primary effects. It also includes some cells which secondary or indirect effects of ITs.

Similarly, we had the hypotheses on the relationship between the benefits of production information systems and the competitive performance indexes.

(P1) Reduction in manufacturing cost, which is realized by the production information systems, improves the competitive performance in manufacturing cost.

(P2) Improved product quality, which is realized by the production information systems, contributes to the competitive performance in conformance quality.

(P3) Overall lead time reduction, which is realized by the production information systems, improves the competitive performance in fast delivery.

(P4) Increased product-mix flexibility, which is realized by the production information systems, leads to high competitive performance in flexibility to change product mix.

[Figure 2] Effects of Information Technologies on PIS

	Reduction in manufacturing cost	Improved product quality	Overall lead-time reduction	Increased product-mix flexibility	Increased product-volume flexibility	Reduced new Product introduction time
CAD						P
CAE		P				P
CAPP	S		P			
LAN	S	S	P	S	S	S
CNC/DNC	P	P	S	S	S	
FMS	P	P	P	P		
Automated R/S		S	P	P		
MRP II	P			P		
Simulation tools		S	S	S	S	S
SPC software	S	P				
Equipment control	P		P	P	P	
Quality database	S	P				
Orders received by EDI			P			
Orders sent by EDI			P			
Suppliers linked by EDI			P			

P: primary effect　　S: secondary effect

(P5) Increased production-volume flexibility, which is realized by the production information systems, leads to high competitive performance in flexibility to change production volume.

(P6) Reduction in new product introduction time, which is realized by the production information systems, improves the competitive performance in speed of new product introduction.

(PC) There are no differences among industries in the hypotheses (P1) to (P6).

(PC) is a complex null hypothesis concerning the inter-industrial comparison on the relationship between benefits of the production information systems and competitive performance.

It should be noted that competitive performance of the plant is influenced by a lot of factors other than computer-based information systems, although they are not shown in Figure 1 for simplicity. One such factor should be information systems based on human communication. More influential to competitiveness are manufacturing strategy, technology development, quality management, Just-in-time production systems, human resource management, organizational behavior, and so on. Therefore, we can only expect the modest relationship between the benefits of information systems and the competitive performance indexes.

3. Research Variables

3.1 Information technology variables (independent variables)

In order to operationalize the analytical framework and the hypotheses in the preceding section, we introduce some research variables as below.

The first cluster of variables is concerned with the level of implementation and utilization of ITs or modules of production information system. They are put together to constitute independent variables explaining benefits of the aggregate production information systems. A simple description of each variable is given as below.

CAD: Implementation of computer aided design
CAE: Implementation of computer aided engineering
CAPP: Implementation of computer aided processes planning
LAN: Introduction of local area networks linking design and engineering stations
CDNC: Implementation of machine tools with computer or direct numerical control
FMS: Implementation of flexible manufacturing systems
ATRS: Implementation of automated retrieval/storage systems
MRP2: Implementation of material requirements planning II (closed-loop MRP)
SIMT: Utilization of simulation tools
SPCS: Utilization of statistical process control software
CPEC: Implementation of computer-based production equipment control
DBQI: Utilization of database for quality information
PCOR: Percentage of customer orders received via electronic data interchange (%)
PPOS: Percentage of purchase orders sent to suppliers by electronic data interchange (%)
PSPL: Percentage of suppliers linked to the plant via electronic data interchange (%)

The last three variables are measured in percentage, like 30, or 75, for the penetration level of EDI into order processing operations. The others are dummy variables, taking only two values, 1, if implemented, or otherwise 0.

3.2 Benefits of the production information systems (*intermediate variables*)

The second set of variables deal with perceived benefits of the aggregate production information systems. They become dependent variables of the regression analysis on ITs and in turn affect competitive performance indexes. The maximum value of each variable is 5, if every respondent in the plant strongly agree that the benefit could be directly attributed to the implementation of ITs and IS modules in the plant, and the minimum is 1, if they strongly disagree that. We use the following six benefits of the production information system as critical intermediate variable:

RMFC: Reduction in manufacturing cost
IPQL: Improved product quality
OLTR: Overall lead time reduction
IPMF: Increased product-mix flexibility
IPVF: Increased production-volume flexibility
RNPI: Reduced new product introduction time

3.3 Competitive performance indexes (*dependent variables*)

The third category of variables is concerned with competitive performance indexes of the manufacturing plant, relative to global competitors in the industry. They are subjectively judged by each plant manager on a five-point Likert scale so that they take discrete integer values from 1 to 5. The following six performance indexes include basic objectives in the production function, that is, cost, quality, delivery, and flexibility:

MFCT: Manufacturing cost
CFQL: Conformance quality
FDEL: Fast delivery
FCPM: Flexibility to change product mix
FCVL: Flexibility to change volume

SNPI: Speed of new product introduction

3.4 Measurement Scales of information systems (*auxiliary variables*)

The last set of variables consists of measurement scales for the utilization of production information in the manufacturing plant. Actual production information systems are based on not only computers and digital networks but also human communication, which jointly determine the competitive performance of the plant. We use the following three measurement scales in order to partly capture the sophistication level of human-based production information systems (see next section for more details):

PFEE: Performance feedback
DPFM: Dynamic performance measures
EXQI: External quality information

4. Data Collection Methods

Data used for the subsequent analyses were gathered through an international joint research on high performance manufacturing (HPM), some of whose results are shown in Schroeder and Flynn (2001). They are concerned with some important aspects of manufacturing plants: environment, human resources, quality, JIT production, IS/ITs, technology development, manufacturing strategy, improvement and performance. We could acquire the data from 164 plants located in five countries: Germany, Italy, Japan, the United Kingdom and the United States. Japan accounts for 46 plants, Italy for 40, Germany for 33, USA for 30, and UK for 21. Just half of total plants are subjectively judged to be world-class and the rest is traditional, ordinary or randomly sampled from machinery, electrical & electronics, and automobile manufacturers. In any plant twenty-six individuals across levels responded to fifteen types of questionnaires that partly share the same questions. The respondents included plant manager, plant superintendent, plant research coordinator, plant accountant, human resource manager, inventory/purchasing manager, information systems manager, production control manager, process engineer, quality manager, supervisors and direct labor. Plant-level data were calculated as an average value of all the valid responses at the plant for each quantitative question item and each scale.

In order to identify which ITs had been implemented and utilized in the plant, the information systems manager was asked whether or not the plant use CAD, CAE, CAPP, LAN, CNC/DNC, FMS, automated retrieval/storage, MRP II, simulation tools, SPC software, computer-based production equipment control, and database for quality information, and the percentage of suppliers linked to the plant via EDI, among others. The inventory/purchasing manager also answered the percentage of purchase orders sent to suppliers by means of EDI and the percentage of customer orders received via EDI.

Benefits of the aggregate production information systems for each plant were measured by averaging those scores which plant manager, plant superintendent and information systems manager subjectively evaluated in terms of twelve possible items. They assessed whether those benefits could be directly attributed to the implementation of the information systems and ITs in the plant on a five-point Likert scale (1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree). In the subsequent analysis we pick up the following six benefits of the information systems: reduction in manufacturing cost, improved product quality, overall lead-time reduction, increased product-mix flexibility, increased production-volume flexibility, and reduced new product introduction time.

In addition, we established measurement scales for the utilization of information systems including human-based communication systems. In this paper we incorporate three scales as follows: *Performance feedback* (responded by plant research coordinator, information systems manager and two supervisors), *Dynamic performance measures* (responded by information systems manager and two supervisors), and *External quality information*: *Supplier Quality Control* (responded by inventory/purchasing manager, quality manager and information systems manager). Schonberger (1986) pointed out that process accounting, assigning burden by lead-time and direct costing were important purposes of information systems, besides scheduling and tracking workflows, in world class manufacturing companies. Each measurement scale was constructed by five to seven question items evaluated on a five-point Likert scale (1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree).

Performance feedback intends to collect information on the kind of feedback used and who receives what. The question to the respondents is that
I receive the following information which helps me to adequately do my job:

1. Quality performance
2. Dependability performance3. Waste reduction
4. New product introduction
5. Financial performance
6. Cost variances
7. Cost of activities*Dynamic performance measures* intends to assess the performance measurement system in terms of changing detail and object of measures and consider whether the feedback is timely. The question items are

1. The performance indicators which we use are strongly related to the planned objectives of the plant.
2. The performance indicators we use change whenever the planned objectives or programs are changed.
3. The detail of the performance indicators we use changes with the situation being addressed.
4. We receive performance measurement in time to perform improvement actions.
5. Our performance measures clearly show objectives and trends.

External quality information: *Supplier Quality Control* measures the availability and the easy use of external quality information regarding suppliers and tests the quality information exchange from suppliers to plant. The question items are

1. Data about quality of parts and components under purchasing consideration are at our disposal.
2. We can easily use data from tests (of quality) conducted by a supplier or by an independent laboratory.
3. We have a system for supplier certification.
4. We require evidence of statistical process control from suppliers of critical parts.
5. Our suppliers have to send us information (documents) certifying the results of specified tests and inspections on materials.

Reliability of those measurement scales was tested according to the Cronbach's alpha coefficient, and construct validity was examined through factor analysis. Flynn et al. (1990) discussed the methodological issues on empirical research in operations management. Matsui (1997, 2000, 2001) showed the details of measurement analysis for the Japanese plants.

Finally, competitive performance was subjectively judged by the plant manager in terms of eleven indexes. Each plant manager was asked to indicate his/her opinion about how the plant compares to its competitors in the industry on a global basis on a five-point Likert scale (1=Poor or low end of the industry, 2=Below average, 3=Average, 4=Better than average, 5=Superior or top of the industry). Corresponding to the benefits of the production information systems we focus on the following performance indexes: manufacturing cost, conformance quality, fast delivery, flexibility to change product mix, flexibility to change volume, speed of new product introduction.

5. Results of the Empirical Analysis

5.1 IT utilization and benefits of production information systems

In this section we shall explore the benefits of IT utilization by regressing each benefit of production information systems on the implementation and utilization of various ITs. The results are shown in Table 1 to Table 6. The columns headed by 'All' give results of regression analysis for the pooled sample. Although the sample size is originally 164, we can use only 77 plants whose IT utilization data are completely available. For the other plants at least one IT utilization variable is missing. The number of plants used for the analysis is 22 for automobile, 29 for electrical & electronics, and 26 for machinery. The automobile plants consist of 5 American, 7 German, 6 Italian and 4 Japanese, including 11 high performance reputations. The electrical & electronics plants consist of 6 American, 2 British, 5 German, 8 Italian and 8 Japanese, including 20 high performance reputations. The machinery plants consist of 2 American, 2 British, 5 German, 10 Italian and 7 Japanese, including 12 high performance reputations. The value of intercept shown in the first row is interpreted as an average or basic benefit level without introducing significant ITs. The coefficient of each IT variable represents how much benefit level would be improved if the IT is implemented or the utilization ratio of EDI increases by 1 percent.

[Table 1] Reduction in manufacturing cost (RMFC)

	All	Automobile	Electrical	Machinery	
Intercept	3.043622 (21.244)**	3.089095 (18.013)**	3.381429 (15.112)**	2.699659 (12.219)**	Figures in the parentheses are t-values.
LAN				0.373858 (1.845)*	
SIMT	0.200095 (1.524)	0.469957 (1.859)*			** significant at the 1% level by one-tailed test
SPCS	0.261665 (1.971)*			0.526096 (2.396)*	
CPEC	0.349947 (2.297)*		0.527965 (2.055)*	0.504977 (2.783)**	* significant at the 5% level by one-tailed test
PPOS	0.003935 (2.122)*	0.006032 (1.591)		0.004677 (2.265)*	
R^2	0.2341	0.2803	0.1353	0.5602	
Adjusted R^2	0.1916	0.2046	0.1032	0.4765	
F-value	5.503**	3.700*	4.223*	6.688**	

According to Table 1, computer-based production equipment control (CPEC) has a significant effect upon the reduction of manufacturing cost (RMFC) except for the automobile industry. CNC/DNC, FMS, and MRP II, however, have no effects upon RMFC for any sample. On the other hand, unexpectedly, SPC software (SPCS) has some impact on the manufacturing cost for the machinery industry and the pooled sample. The percentage of purchase orders sent to suppliers by means of EDI (PPOS) also has an impact upon the manufacturing cost significantly for the machinery and the pooled sample, and marginally for the automobile industry. LAN for the machinery and simulation tools (SIMT) for the automobile shows moderate impacts upon the cost. The regression model for the machinery industry has more significance and explanatory power than those for the automobile and the electrical & electronics industries.

[Table 2] Improved product quality (IPQL)

	All	Automobile	Electrical	Machinery	
Intercept	3.349070 (36.077)**	2.789222 (8.071)**	3.499722 (23.614)**	3.060000 (20.365)**	Figures in the parentheses are t-values.
CAE				0.441667 (2.108)*	
ATRS		0.504370 (1.433)			** significant at the 1% level by one-tailed test
SPCS	0.391322 (2.801)**		0.520278 (2.688)**	0.818333 (3.116)**	
DBQI		0.495630 (1.408)			* significant at the 5% level by one-tailed test
R^2	0.0947	0.1168	0.2111	0.3397	
Adjusted R^2	0.0826	0.0238	0.1819	0.2823	
F-value	7.846**	1.256	7.224*	5.916**	

Table 2 is concerned with the effects of ITs on improved product quality (IPQL). SPC software (SPCS) has a highly significant effect except for the automobile industry. Particularly for the machinery industry, the estimated coefficient surpasses 0.8 and significantly different from zero. CAE shows a significant impact on the product quality for the machinery industry only. Database for quality information (DBQI) might improve the product quality for the automobile industry. An unexpected effect on the product quality is detected in automated retrieval/storage (ATRS) for the automobile industry. The regression model for the automobile industry, however, poorly performs with extremely low significance and small explanatory power.

[Table 3] Overall lead-time reduction (OLTR)

	All	Automobile	Electrical	Machinery	
Intercept	3.653143 (42.087)**	3.457124 (23.733)**	3.714770 (22.277)**	3.194780 (14.014)**	Figures in the parentheses are t-values.
CAPP		0.344812 (1.764)*			
LAN				0.459591 (2.119)*	** significant at the 1% level by one-tailed test
FMS	0.255941 (2.180)*		0.291572 (1.615)		
SIMT	0.290810 (2.462)**	0.462796 (2.338)*	0.363902 (1.986)*		* significant at the 5% level by one-tailed test
CPEC				0.283503 (1.461)	
PSPL				0.007462 (1.557)	
R^2	0.1561	0.3508	0.1969	0.3368	
Adjusted R^2	0.1333	0.2824	0.1351	0.2463	
F-value	6.845**	5.133*	3.187	3.724*	

From Table 3, we can find that CAPP for the automobile industry and LAN for the machinery industry have significant effects on the overall lead-time reduction (OLTR), while

FMS influences the lead-time significantly for the pooled sample and marginally for the electrical & electronics industry. Automated retrieval/storage (ATRS), however, has no significant effect for any sample. Computer-based production equipment control (CPEC) and the percentage of suppliers linked to the plant via EDI (PSPL) have marginal effects upon the lead-time for the machinery only. We also find that simulation tools (SIMT) have a highly significant impact upon OLTR for the pooled sample, as well as for the automobile and the electrical & electronics industries. The regression model for the electrical & electronics industry, however, doesn't perform well with low explanatory power.

Table [4] Increased product-mix flexibility (IPMF)

	All	Automobile	Electrical	Machinery	
Intercept	3.152840 (29.225)**	2.591967 (11.085)**	2.822503 (10.831)**	1.678852 (2.717)**	Figures in the parentheses are t-values.
CAD				0.718363 (1.362)	
LAN				0.586815 (2.485)*	** significant at the 1% level by one-tailed test
CDNC				0.609348 (2.213)*	
FMS				0.458319 (2.035)*	* significant at the 5% level by one-tailed test
MRP2		0.323408 (1.410)			
SIMT	0.355768 (2.490)**	0.464256 (2.165)*	0.326098 (1.461)		
CPEC			0.468361 (1.817)*		
PCOR	0.002630 (1.467)	0.006919 (2.460)*	0.005982 (2.443)*		
PPOS	0.003422 (1.582)				
R^2	0.1837	0.4219	0.3691	0.5124	
Adjusted R^2	0.1502	0.3256	0.2934	0.4195	
F-value	5.477**	4.380*	4.875**	5.516**	

According to Table 4, significant effects on increased product-mix flexibility (IPMF) are found of FMS for the machinery industry and computer-based production equipment control (CPEC) for the electrical & electronics industry. The effect of MRP II (MRP2) on the product-mix flexibility is marginal for the automobile industry. On the other hand, unexpected impacts on the product-mix flexibility are detected in simulation tools (SIMT) and the percentage of customer orders received via EDI (PCOR) except for the machinery industry, LAN and CNC/DNC (CDNC) for the machinery industry, and marginally CAD for the machinery industry and the percentage of purchase orders sent to suppliers by means of EDI (PPOS) for the pooled sample. The regression models for the electrical & electronics and the machinery industries are both highly significant, but they completely differ in the critical independent variables.

Table 5 shows that computer-based production equipment control (CPEC) significantly increases the production-volume flexibility for the electrical & electronics industry only. Rather, there found some unexpected influences on the production-volume flexibility. Highly significant effects are percentage of customer orders received via EDI (PCOR) except for the machinery industry and database for quality information (DBQI) for the automobile industry. MRP II (MRP2) has a significant impact upon the production-volume flexibility for the automobile and the machinery industries. Simulation tools (SIMT) for the pooled sample and CNC/DNC (CDNC) for the machinery industry marginally increase the production-volume flexibility. The positive effect of FMS on the production-volume flexibility seems to be questionable. The regression model of increased production-volume flexibility (IPVF) is highly significant for every sample, particularly for the electrical & electronics industry.

Table [5] Increased production-volume flexibility (IPVF)

	All	Automobile	Electrical	Machinery	
Intercept	3.075996 (29.271)**	1.867401 (5.527)**	2.897274 (14.425)**	2.721592 (11.956)**	Figures in the parentheses are t-values.
CDNC				0.405259 (1.462)	
FMS	0.277993 (1.947)*	0.476578 (2.164)*		0.584714 (2.657)**	** significant at the 1% level by one-tailed test
ATRS		0.435960 (1.500)			
MRP2		0.480729 (2.078)*		0.392038 (1.820)*	* significant at the 5% level by one-tailed test
SIMT	0.222660 (1.633)				
CPEC			0.468344 (2.109)*		
DBQI		0.791784 (3.124)**			
PCOR	0.004778 (2.956)**	0.008282 (3.117)**	0.008109 (3.887)**		
R^2	0.2575	0.6392	0.4693	0.4600	
Adjusted R^2	0.2270	0.5265	0.4284	0.3864	
F-value	8.438**	5.670**	11.494**	6.247**	

From Table 6, we can find that upon the reduction in new product introduction time (RNPI) CAD has a significant effect for the machinery industry only, while CAE exercises no impacts for any sample. In this case, there are many secondary effects of ITs. They are FMS and SPC software (SPCS) for the machinery industry and the pooled sample, percentage of customer orders received via EDI (PCOR) for the automobile industry, and marginally MRP II (MRP2) for the machinery industry and CNC/DNC (CDNC) for the electrical & electronics industry. The regression model for the machinery industry has more significance and explanatory power than those for the automobile and the electrical & electronics industries. There found no critical ITs that significantly reduce new product introduction time for the electrical &electronics industry. In this case, important independent variables are completely different from industry to industry.

These results are clearly against the hypothesis (BC). For every benefit of production information systems there are considerable differences among industries in the effects of IT utilization. In other words, the relationship between IT utilization and their benefits differs from industry to industry. The regression model for the electrical & electronics shows low values in both the coefficient of determination and the level of significance, and it includes few IT that has significant effect on the benefits of production information systems.

This suggests that there are several ITs or modules of production information systems which do not necessarily show the hypothesized effects. For example, CAE has no significant effect on new product introduction time; FMS is not effective to reduce the manufacturing cost; automated retrieval/storage does not necessarily decrease the inventory level. On the other hand, there found many unexpected or secondary effects of IT utilization. LAN and EDI have been recognized as a source of almost every benefit of production information systems. Some examples of the unexpected effects are EDI linkage with suppliers upon product differentiation, simulation tools upon customer service, and FMS, MRP II, database for quality information and the percentage of customer orders received via EDI upon production-volume flexibility.

[Table 6] Reduced new product introduction time (RNPI)

	All	Automobile	Electrical	Machinery	
Intercept	2.846532 (24.004)**	2.702929 (13.478)**	3.242424 (16.660)**	1.179342 (2.026)*	Figures in the parentheses are t-values.
CAD				1.378217 (2.531)**	
CDNC			0.350168 (1.417)		** significant at the 1% level by one-tailed test
FMS	0.362789 (2.485)**			0.801842 (3.993)**	
MRP2				0.352150 (1.593)	* significant at the 5% level by one-tailed test
SPCS	0.400473 (2.736)**			0.514178 (2.094)*	
PCOR		0.006235 (1.923)*			
R^2	0.1528	0.1560	0.0693	0.5403	
Adjusted R^2	0.1299	0.1138	0.0348	0.4527	
F-value	6.673**	3.697	2.009	6.169**	

5.2 Benefits of production information systems and competitive performance indexes

In this section we comparatively examine the relationships between the benefits of production information systems and competitive performance indexes by using a simple correlation analysis. The results are shown at the upper part of Table 7. It has 36 cells, each corresponding to a pair of one benefit and one competitive performance index. The cells include the name of the industries for which significant correlations are found between the benefit and the competitive performance index. They are judged to support the hypothesis (P3) for the automobile and the electrical & electronics industries and the hypotheses (P4) and (P5) for the automobile and the machinery industries. What is the most surprising is that reduction in manufacturing cost, improved product quality, and reduced new product introduction time by production information systems do not significantly correlate with the corresponding competitive performance indexes for any industry.

In summary, the benefits of production information systems do not necessarily connect with the improvement in competitive performance directly. Competitive performance depends on many factors other than computer-based information systems: for instance, human-based communication systems, organizational behavior, human resource management, quality management, JIT production, technology development, manufacturing strategy and so forth. Production information systems are just one source of core competence, although they have increasingly become powerful in some cases. Another puzzle is that the benefits of production information systems sometimes have multiple effects on the competitive performance indexes. The pattern of the multiple effects differs from industry to industry. This supports that the complex null hypothesis (PC) should be rejected.

[Table 7] Correlation analysis on the benefits of information systems

Benefits of IS	RMFC	IPQL	OLTR	IPMF	IPVF	RNPI
(Competitive performance)						
MFCT						
CFQL					E	
FDEL			A **E**	E	A **E**	
FCPM				A **M**	**M**	
FCVL				A **M**	A M	
SNPI				M		
(IS measurement scales)						
PFEE		**M**			M	**M**
DPFM		M				
EXQI	**A**	E **M**		A		M

The capital letters represent the initial of the nation where significant correlations are detected by two-tailed test at the 5% level. The bold capitals mean the correlations are significant at the 1% level.

A=automobile industry E=electrical & electronics industry M=machinery industry

6. Concluding Remarks

In this paper we made hypotheses concerning the relationships among IT implementation and utilization, benefits of the aggregate production information systems and competitive performance indexes, (B1) to (B6) and (P1) to (P6), and further constructed complex null hypotheses concerning the differences among industries in the original hypotheses, (BC) and (PC). Main results we can derive from the regression and correlation analyses are summarized as follows:

a) There are considerable differences in the benefits of IT implementation and utilization among industries.

b) There are several ITs which do not necessarily show the hypothesized effects: CAE, FMS, and automated retrieval/storage systems.

c) There are many unexpected or secondary effects of IT utilization.

d) There are considerable differences in the relationships between the benefits of production information systems and the competitive performance indexes among industries.

e) The benefits of production information systems do not necessarily connect with the improvement in competitive performance indexes.

The reasons for the comparative differences in determining the benefits of ITs are worthy to be considered. Most of the differences could be attributed to certain measurement problems on the benefits of production information systems, which were subjectively evaluated by plant manager, plant superintendent and information systems manager on a five-point Likert scale. Some factors might influence their perception and evaluation.

The poor performance of the regression models for the electrical & electronics industry might be explained by the routinization of ITs. Although the plants in the industry have heavily invested in ITs, there is no big difference in the evaluated benefits of production information systems among three industries. The average score over benefits of the aggregate production information systems is 3.75 for the electrical & electronics industry, compared with 3.53 for the automobile industry and 3.48 for the machinery industry. By a simple analysis of variance, we cannot reject the null hypothesis that the average score is the same for those three industries at the 1% level. When utilization of sophisticated ITs is a matter of course, perception of the extent that individual software or hardware contributes to the benefits tends to be blunt.

Another possibility is the influence of human-based information systems. The lower part of Table 7 includes the correlation coefficients between the benefits of production information systems and four measurement scales concerning information systems in a broad sense. Six pairs of the benefits and the measurement scales are significantly correlated for the machinery industry. Two correlation coefficients are significantly different from zero for the automobile industry. Only one correlation between improved product quality and external quality information is significant for the electrical & electronics industry. We think that the perception of the benefits of computer-based production information systems should be affected in some extent by the relationship between ITs and human communication, or the roles of ITs in production information systems. One possibility is that machinery plants tend to think that computer-based and human-based information systems are dependent or complementary, as electrical & electronics plants may consider the relationship as independent or substitutive, being aware of the limitations facing with ITs.

In addition, we could find that the benefits of production information systems are closely related with the measurement scales concerning human resource management, quality management, JIT production, and manufacturing strategy for the Japanese sample, as shown in Matsui (1997, 2001). These elements of production systems may affect the perception of the benefits. This possibility should be explored further along with investigations into determining the competitive performance of manufacturing companies from global perspectives.

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