Reexamining the Benefits of Information Systems in Japanese Manufacturing Companies

Osam Sato

Yoshiki Matsui

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Osam Sato
Faculty of Business Administration
Tokyo Keizai University
Kokubunji, Tokyo, Japan
osamsato@tku.ac.jp

Yoshiki Matsui
International Graduate School of Social Sciences
Yokohama National University
Yokohama, Kanagawa, Japan
ymatasui@ynu.ac.jp

Abstract

It is quite reasonable to presuppose that information systems provide various benefits to manufacturers. But we don't have much evidence on the benefits especially in Japanese manufacturing. In this paper we investigated the hypotheses presented by Matsui and Sato [6] [7] concerning the effects of information technologies and information systems upon manufacturing benefits with slightly different analytical approach and samples. We introduced more precise measure for implementation of information technologies and information systems, and divided the sample consisting of forty-six Japanese manufacturing companies into two sub-sample, world-class and random. The result of our analysis endorsed some of the propositions proved by Matsui and Sato [7], and provided new evidence to the hypotheses that utilization of statistical process control software improves product quality, implementation of computer-based production equipment control increases product-mix flexibility, and utilization of database for quality information and an increase in the percentage of external units electronically linked with the plant improve customer service. It also suggested additional hypotheses. Further, we discovered different relationships of information systems implementation with manufacturing benefits between world-class and randomly sampled companies.

1. Introduction

Market competition in manufacturing sectors is becoming fierce in these days. The globalization of economy expands market for manufacturing goods, but at the same time it enlarges the area of competition among manufacturers. One of the most important weapons for manufacturing firms is information technologies and information systems, which are hereafter abbreviated as IS. IS potentially gives many benefits and competitive advantages to manufacturers, if it is appropriately used. These benefits include reduction in manufacturing cost, decrease in inventories, overall lead-time reduction, improvement in on-time deliveries, increased product-mix flexibility, increased production-volume flexibility, reduced new product introduction time, improved customer service, increased level of cooperation with customers and suppliers, improved product differentiation, and improved product quality. These benefits become critically dependent on the implementation of IS, although they are certainly affected by various factors except IS.

In this paper we intend to focus effects of IS upon these benefits in Japanese manufacturing plants. According to Matsui and Sato [7], appropriate implementation of production IS had strong impact upon these benefits in Japanese manufacturing companies. It also shows that the effect varied among IS employed. For example, implementation of computer-based production equipment control (CPEC) has strong impact on reduction of manufacturing cost (RMFC), but implementation of automated retrieval/storage systems (ATRS) has little impact on RMFC. Because the study used only one sample for Japanese manufacturers, and because there are few relevant studies, we investigate more about those propositions and extend above empirical research further to answer the following questions in this paper:

1. Did the implementation and experience of production IS contribute to a set of manufacturing benefits in Japan?
2. What kind of IS has more impact on each benefit in the Japanese manufacturing plants?
3. Did world-class companies enjoy IS benefit more than others in Japan?
4. Are propositions that Matsui and Sato [6] [7] presented robust enough?

2. Research Background

One of the most important weapons to compete against rivals in global manufacturing markets is application of IS. As Heizer and Render [2, p.272] described, "firms that know how to use technology find it an excellent vehicle for obtaining competitive advantage." Knowing how to apply and use IS to gain maximum benefit has been, therefore, a critical subject for most manufacturing companies for last decades.

However, we cannot find much research concerning IS benefits for Japanese manufacturing companies. Matsui and Sato [4] [5] [6] [7] proposed an analytical framework and research hypotheses concerning benefits of production information systems for manufacturing companies. Matsui and Sato [7] did an empirical research about IS benefits for Japanese manufacturing plants. It revealed that implementation of computer aided design (CAD), computer aided processes planning (CAPP), machine tools with computer or direct numerical control,

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material requirements planning II (closed-loop MRP), computer-based production equipment control, utilization of statistical process control software, purchase orders sent to suppliers by electronic data interchange, and high percentage of external units (including suppliers, distributors, company plants, banks, etc.) that were electronically linked with the plant have contributed to Japanese manufacturing firms.

The results endorsed some of their hypotheses about benefits of each information technology (IT), but failed to prove others. The hypotheses are summarized in Table 9 below, where P's and S's in the cells stand for primary and secondary effects of each IT, respectively. The merits of their research were the relatively high fitness of the model to their data, and the potential for international comparison partly made in Matsui and Sato [4] [6] among others. On the other, it has certain limitations that were the paucity of samples available, and some incongruence to their hypotheses.

3. Hypotheses

As discussed in the above research as well as others including Hammer and Champy [1], Schroeder and Flynn [8] etc., IS is supposed to have positive impact on manufacturing performance. For example, CAD is supposed to contribute shortening design phase of new product development, improve design quality and help automation of production process. These reduce cost for new product introduction. CAE seems to improve reliability of parts and finished goods as well as hasten the new product development process. CAPP has a main effect on the reduction in cycle time, which in turn reduces manufacturing cost. The effect of LAN could be widespread from the automatic control of machine tools and robotics through various flows of production information to attain CIM.

However, the level or degree of IS impact may be differing among plants, companies, industries, and countries. One reason that Matsui and Sato [7] failed to endorse their hypotheses completely might come from the difference among sub-samples. For example, high performance companies may employ IT wiser than other companies. As a result, if we divide the Japanese sample into world-class plants and others, world-class plants may reveal stronger relationships between IT implementation and the benefits. If we employ more samples to investigate the difference, we may be able to find different or stronger relationships between IS and manufacturing benefits. Therefore, our research hypotheses will be expressed as follows:

H1: World-class manufacturers (WCM) show stronger relationships between implementation of IT and the benefits on manufacturing than other firms.

H2: More hypotheses suggested by Matsui and Sato [6] [7] are proved if we limit samples to WCM.

We shall study these hypotheses, resting on our empirical data for the Japanese manufacturing companies.

4. Data

4.1 Data Collection Procedure

We have conducted a set of questionnaire surveys on Japanese manufacturing plants. We selected plants from machinery, electrical & electronics, and automobile manufacturers located in Japan, visited those plants and asked their cooperation to collect data. We left a set of questionnaires in the plants and recovered them back later.

Table 1
Abbreviations of IS used in this study

Abbreviation	Explanation
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
MRP1	Implementation of material requirements planning I (type one MRP)
MRP2	Implementation of material requirements planning II (closed-loop MRP)
JITS	Utilization of just-in-time software
SIMT	Utilization of simulation tools
SPCS	Utilization of statistical process control software

Our Japanese sample accounts for forty-six plants. Among them, thirty-two plants are subjectively judged to be world-class and the rest are 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 measurement scale.

4.2 Measures of IS Implementation

This study deals with eighteen information technology variables concerning CAD, CAE, CAPP, NC machine tools, FMS, computer-based production equipment control, automated retrieval/storage, MRP I and II, simulation tools, JIT software, SPC software, database for quality information, LAN, and EDI. Twelve independent variables measure implementation of these IS. They are listed in Table 1 with abbreviations. In order to identify which IS had been utilized in the plant, the IS manager was asked the year when the plant had implemented each IS listed in Table 1. We calculated the usage length from implementation or experience of each IS by subtracting the year from 2000, and regarded it as a measure of IS implementation. If a plant had not implemented certain IS, we assigned a zero to the variable. These measures have more information on the implementation of IS than the dummy variables employed in Matsui and Sato [4] [5] [6] [7].

Table 2
Additional Scales of IS Implementation

Abbreviation	Explanation
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 (%)
PELL	Percentage of external units electronically linked with the plant (%)
CPEC	Implementation of computer-based production equipment control
DBQI	Utilization of database for quality information

We appended six more measures of IS implementation in Table 2. Four variables, customer orders received via EDI (PCOR), purchase orders sent to suppliers by EDI (PPOS), suppliers linked to the plant via EDI (PSPL), and external units (including suppliers, distributors, company plants, banks, etc.) electronically linked with the plant (PELL), were measured in percentage. PSPL and PELL were directly asked to the IS manager. The inventory/purchasing manager also answered PCOR and PPOS. These variables range from 0 to 100 as percentage. The other two variables, implementation of computer-based production equipment control (CPEC) and utilization of database for quality information (DBQI), are dummy variables and take only two values, either 1 if implemented or 0 otherwise.

As a result, we have three types of data, i.e., year, dummy, and percentage. Because the range and distribution are different among variables, we normalize those variables, which can delete the size effect and make easy direct comparisons of the data. We will use the normalized variables as scales of IS implementation in the subsequent analysis.

4.3 Measures of Benefits

Manufacturing benefits of IS implementation are listed in Table 3. They are designed as five-point Likert scales (1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree), and added to our questionnaire. These questions are asked to an IS manager, a production manager, and a plant superintendent of each plant. They assessed subjectively whether the benefits could be directly attributed to the implementation of particular information system in the plant on a five-point Likert scale. We calculated average values of the responses from these three persons to construct manufacturing benefit measures at the plant level.

Table 3
Abbreviations of IS Benefits Measured

Abbreviation	Explanation
RMFC	Reduction in manufacturing cost
DINV	Decrease in inventories
OLTR	Overall lead time reduction
IOTD	Improvement in on-time deliveries
IPMF	Increased product-mix flexibility
IPVF	Increased production-volume flexibility
RNPI	Reduced new product introduction time
ICSV	Improved customer service
ILCC	Increased level of cooperation with customers
ILCS	Increased level of cooperation with suppliers
IPDF	Improved product differentiation
IPQL	Improved product quality

5. Research Method

We investigate our hypotheses about the effect of implementation of IS on manufacturing benefits by correlation analysis, using the above data. Because all data are real measures, Pearson’s true product-moment correlation is appropriate for this analysis. We consider manufacturing benefits as dependent variables, and IS implementation as independent variables. We compare results of correlation analysis among the following cases:

1. Use data for all forty-six plants
2. Use data for thirty-two world-class plants
3. Use data for fourteen randomly sampled plants

Generally speaking, the smaller the sample size is, the higher the correlation coefficient becomes to attain certain significance level of rejecting the null hypothesis that the correlation is zero. Therefore, we compare the levels of significance as well as the absolute values of the coefficients.

We did not employ regression analysis that tried to explain variation of manufacturing benefits with a set of IS implementation variables because of high correlation among independent variables.

Table 4
Comparison of Correlation Coefficients (1)

IS \ Benefits	RMFC			DINV	OLTR	
	ALL	WCM	OTHER	ALL	ALL	WCM
CAE			0.657*			
CAPP	0.315*	0.356*				0.402*
LAN					0.341*	
CDNC	0.351*					
MRP2			-0.564*			
JITS					0.370*	
SPCS		0.392*				
CPEC	0.361*	0.451+		0.311*		
DBQI	0.424+	0.535+			-0.505+	
PCOR	0.357*		0.777*			
PSPL					0.337*	

+ significant at the 1% level by one-tailed test
* significant at the 5% level by one-tailed test

Table 5
Comparison of Correlation Coefficients (2)

IS \ Benefits	IOTD			IPMF		IPVF	
	ALL	WCM	OTHER	ALL	WCM	ALL	WCM
CAE			0.670+				
CAPP		0.407*					
LAN				0.328*			
FMS				0.353*			
ATRS				0.427+	0.425*		
JITS				0.561+	0.575+	0.350*	
SIMT			0.561*	0.336*		0.370*	
SPCS				0.334*		0.343*	0.355*
CPEC					0.390*		
DBQI			0.578*				
PCOR	0.371*						
PSPL	0.421+	0.487+					

+ significant at the 1% level by one-tailed test
* significant at the 5% level by one-tailed test

6. Results of Analysis

6.1 Interpretation of Negative Coefficients

Tables 4 to 7 compare the results of correlation analysis. They show only significant results. We find that some of IS have significant negative effects on manufacturing benefits, although we did not originally assumed significant and negative correlation coefficients. Hence, we need to discuss about them first of all. Implementation of MRP II significantly correlates with the increase in manufacturing cost in non-WCM plants, shown in Table 4. We may be able to interpret this finding as MRP II is so expensive and complex for non-WCM plants to use that the introduction could complicate their processes and increase their costs for production. The correlation coefficient between DBQI (database for quality information) and OLTR (overall lead time reduction) is also significantly negative for the whole sample. We can interpret the result as the existence of tradeoff between utilization of quality information database and delivery performance.

Table 6
Comparison of Correlation Coefficients (3)

IS \ Benefits	RNPI			ICSV		ILCC	
	ALL	WCM	OTHER	ALL	WCM	ALL	WCM
CAD	0.376*						
CAE	0.362*		0.699+				
CAPP							0.433*
LAN	0.368*						
FMS	0.321*			0.320*			
ATRS	0.329*	0.438*		0.297*	0.375*		
MRP2	0.363*	0.405*					
JITS	0.448+	0.485+					
SIMT	0.340*						
CPEC							0.356*
DBQI				0.423+	0.468+	0.325*	0.373*
PELL				-0.332*	-0.373*	-0.406+	-0.462+

+ significant at the 1% level by one-tailed test
* significant at the 5% level by one-tailed test

Table 7
Comparison of Correlation Coefficients (4)

IS \ Benefits	ILCS			IPDF		IPQL	
	ALL	WCM	OTHER	ALL	WCM	ALL	WCM
CAE			0.647*				
ATRS	0.354*	0.365*		0.301*	0.383*		
SIMT	0.294*						
SPCS							0.376*
CPEC	0.477+	0.431*					
DBQI						0.301*	

+ significant at the 1% level by one-tailed test
* significant at the 5% level by one-tailed test

We also find significant negative correlation coefficients of PELL (percentage of external units that were electronically linked with the plant) with ICSV (improved customer service) and ILCC (increased level of cooperation with customers) for the whole sample and WCM sample. The results reveal that the usage of electronic link to external units decreases customer service and cooperation with customers. Most customers for the plants are not consumers but wholesalers or other manufacturing companies. Usually the number of customers is considerably limited, and both customers and plants prefer face-to-face contacts rather than electronic linkages.

We tend to presuppose that introduction of IS *always* provide benefits in *all aspects* in a plant. But our results imply that this is not true. External links may be good in many cases, but they are not necessarily for customer service and cooperation with customers.

6.2 Do the relationships become stronger if we limit samples?

After we calculate correlation coefficients and compare the significance, we can identify five patterns of significance in correlations for three samples. They are summarized in Table 8. In Table 8, "significant only when …" means that a significant coefficient appears only one of three columns (corresponding to samples) for each dependent variable. "More significant when …" represents significant coefficients appear two of three columns for each dependent variable. We actually compared the whole sample with WCM sample or non-WCM sample. The last pattern, "Significant regardless sample limitation," means significant coefficients appear in all columns for each dependent variable. We counted the number of these cases in Table 4 through Table 7.

Generally speaking, the larger sample size becomes, the easier it is to get significant coefficients. Therefore, the number of significant cases tends to be large for the whole sample than for the WCM sample, and in turn for the WCM sample than for the non-WCM sample. The distribution of the number of significant cases in Table 8 is intuitively reasonable.

If a case is in pattern 1, then the relationship is consistent but not so robust. If a case is in pattern 2, then it means it is specific to WCM plants only. It may be the

Table 8
Patterns of Significance

Pattern		Sample size	Number of significance
1	Significant only when we use all data	46	19
2	Significant only when we limit to WCM data	32	8
3	Significant only when we exclude WCM data	14	6
4	More significant when we limit to WCM data	32, 46	18
5	More significant when we exclude WCM data	14, 46	2
6	Significant regardless sample limitation	46, 32, 14	0

Table 9
Matching hypotheses and two empirical results

IS \ Benefits of PIS	RMFC	DINV	OLTR	IOTD	IPMF	IPVF	RNPI	ICSV	ILCC	ILCS	IPDF	IPQL
CAD				P			P	*	*		*P	
CAE				P			P				P	P
CAPP	*4		*2P	*2				S	*2			
LAN			P		*			S				
CNC/DNC	*P											P
FMS	P		P		P	*		S				P
Automated R/S		P	P	P	*4P	*	*4	*4S		4	*4	*
MRP I	P	P			P	*		*				
MRP II	*P	P			P		4					
JIT software	P	P			*4		*4		*	*	*	
SPC software	*2					4		P				2P
Equipment control	*4		P		2P	P		*S	2	4		
Quality database	4					*		4S	4			*P
Orders received by EDI			P	P				S	*			
Orders sent by EDI	*		P	P		*	*	*S	*	*	*	*
Suppliers linked by EDI			P	*2P				S				
Units electronically linked	*		P	P			P	4S	*4P	P	P	

1. Hypotheses by Matsui and Sato [7] P: primary effect S: secondary effect
2. * Significant results by Matsui and Sato [7]
3. Significant Relationship in this paper 2: pattern 2 4: pattern 4

secret source of excellence in the WCM plants. Or, it might represent a kind of hurdle a manufacturing plant must overcome to be world class. This pattern supports our hypothesis H1. If a case is in pattern 3, it is a strong relationship we find for non-WCM plants only. It may be a false application of IS to the manufacturers. If a case is in pattern 4, then the relationship is consistent but it appear more explicitly in WCM plants. These are cases that our hypothesis H2 implies. If a case is in pattern 5, we cannot find the correlation coefficient is not high for the WCM sample, and there is certainly significant relationship for non-WCM plants, as compared to the whole sample. It would be specific to non-WCM plants. If a case is in pattern 6, the relationship is consistent and robust regardless of plant type (either WCM or not). Unfortunately we cannot find this pattern from Table 4 through Table 7.

Now we go for the examination of our hypotheses, H1 and H2. We compare the cases in pattern 2 and pattern 4 with hypothesized effects presented in Matsui and Sato [6] [7] in Table 9. "P" stands for a hypothesized relationship as a primary effect. "S" means the relationship is hypothesized as a secondary effect. "*"indicates that the relationship was significant at 5% level in Matsui and Sato [7]. "2" and "4" mean the relationship is classified into pattern 2 and pattern 4, respectively, in Table 8.

Table 10 counts the number of cases according to the combination of marks (*, 2, 4, P and S) in Table 9. The combination takes seven different forms or types. For instance, the hypothesized relationships that were not proved by Matsui and Sato [7] but acknowledged by this correlation analysis are to be categorized into type 3. These relationships potentially include four different combinations of marks in Table 9 as follows: 2P, 4P, 2S, and 4S. Actually the table includes the entries of 2P and 4S only.

According to these tables, we can induce some important results concerning the hypotheses, H1 and H2. Firstly, CPEC contributes IPMF, that is, implementation of computer-based production equipment control increase product-mix flexibility. This sounds natural, but the point is that this relationship is applicable only to WCM plants. In fact, we find a reverse relationship for non-WCM plants, although it is not significant. Implementation of computer-based production equipment control might decrease product-mix flexibility for non-WCM plants. This associates the old CIM model, which was punctuated by a series of failures and results that fell below expectations.

Secondly, DBQI contributes ICSV, that is, utilization of database for quality information improved customer service. This also sounds natural and associates quality assurance activities by WCM plants. This relationship is labeled "4S" in table 9. Matsui and Sato [7] hypothesized the relationship as secondary, and Table 6 shows it is significant for the whole sample and highly significant for the WCM sample (p-value is 0.007). On the other hand, the non-WCM sample shows negative relationship between DBQI and ICSV, but the correlation coefficient is almost zero.

Thirdly, PELL effects ICSV. But the relationship is negative, as we have already discussed in the previous section.

Finally, SPCS contributes to IPQL, i.e., utilization of statistical process control software improved product quality. This is marked as "2P" in Table 9. Matsui and Sato [6] [7] hypothesized the relationship as primary, and this relationship is strongly supported for the WCM sample only. Certainly, the relationship is negative for the non-WCM sample, although not significant. At least utilization of statistical process control software doesn't seem to improve product quality of non-WCM plants. Unless they use statistical process control software appropriately, it won't contribute to quality performance. This could be the case for non-WCM plants.

Table 10
Summary of Congruence Between Hypotheses and Results

Type		Mark	Number
1	Proved by Matsui and Sato [7]	*P or *S	6
2	Proved by this analysis	2P or 4S	4
3	Proved by both empirical studies	*2P, *4P, or *4S	5
4	Not hypothesized but both empirical studies agree	*2 or *4	4
5	Hypothesized but unproved	P or S	40
6	Appear only in Matsui and Sato [7]	*	21
7	Appear only in this analysis	2 or 4	7

The marks appear in table 9.

7. Conclusions

In this paper we investigated hypotheses set by Matsui and Sato [6] [7], and conducted an additional empirical analysis with different approach and samples. We can answer to the questions that we addressed in the introductory section of this paper as follows:

1. Did the implementation and experience of production IS contribute to a set of manufacturing benefits in Japan?
   Our analysis gives additional support for the proposition.

2. What kind of IS has more impact on each benefit in Japanese manufacturing plants?
   Table 4 through Table 7 summarize significant relationships between IS implementation and manufacturing benefits.

3. Did world-class plants enjoy IS benefit more than others in Japan?
   As table 8 shows, world-class companies proclaim more significant relationships between certain IS implementation and benefits than others.

4. Are propositions that Matsui and Sato [6] [7] presented

robust enough?

Some of them are endorsed by our analysis as shown in table 9 and they seems robust to us. There are still, however, others which remain unproved.

We took up a set of hypotheses that Matsui and Sato [6] [7] had raised, and verified them through different analytical approach and different samples. Human beings don't know the truth of the universe. In order to approach the truth, we need to accumulate empirical research hopefully from different points of view along with different analytical tools and different samples to verify our hypotheses, and then refine our hypotheses if accumulated empirical results are not consistent with them. Straub [9] recommended multi trait multi method (MTMM) as an empirical research approach, and Mahmood and Soon [3] applied the method to IS. Although this research is not MTMM, precisely speaking, it investigates a set of hypotheses presented by Matsui and Sato [6] [7] from a different method. Regression results by Matsui and Sato [4] [5] [6] [7] tend to be inconsistent depending on samples employed in the analysis. This is especially true if we don't have enough sample size, as was the case of Matsui and Sato [7]. As a result, true hypotheses might be rejected with the analysis, or false hypotheses might be accepted. We tried to verify the findings of Matsui and Sato [7].

In fact, our analysis supports five hypotheses proved by Matsui and Sato [7], but fails to endorse six hypotheses proved by the paper according to Table 10. We successfully find evidences for four additional hypotheses that Matsui and Sato [7] hypothesized but failed to support. The most important finding is that WCM sample insisted the significance of some relationships, but non-WCM sample implied reverse relationships. These suggest critical differences between WCM plants and others. Besides, we can support four more relationships that Matsui and Sato [7] revealed but had not hypothesized. Because these relationships seem robust, we may be able to establish them as new hypotheses.

We need to repeat more empirical analyses to confirm the robustness of these hypotheses, verify and refine them hopefully from different points of view with different analytical approaches, and establish new set of hypotheses. There are also some weaknesses in our study. Firstly, samples used are not large enough (see Table 8). Secondly, many samples are the same as those of Matsui and Sato [7]. Thirdly, the method we employ to establish our measures needs to be examined more. Empirical results might be affected by what kind of measures we used in the study, and this caveat is also applicable to our study. At last we need to examine the relationships that non-WCM plants enjoy but WCM plants do not. These are pattern 3 and pattern 5 in Table 8. We need to investigate why WCM plants fail to enjoy these benefits from IS. These will be next research topics for us.

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