JIT quality matrices for strategic planning and implementation

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Introduction

The design of manufacturing systems requires a proper analysis of the issues involved from strategic, tactical, and operational perspectives. There are many manufacturing strategies that have surfaced recently which are the major force behind the success of an enterprise both in Japan and the USA[1-4]. Prasad[1] addresses tactical JIT criteria that can be used to support a productivity improvement strategy in a factory of the future. Tompkins[2] outlines 25 requirements associated with manufacturing system design that, he suggests, must be addressed. Some of these requirements include cost, capacity, marketing, inventory, quality, flexibility, and integration. At a management level, Hirano[4] cites how the manufacturing functions can be used to support a productivity improvement strategy. This includes strategies such as marketing, sales, engineering, and manufacturing, each with a supportive role to fulfil the top strategic mission.

In order to enhance competitiveness and efficiency of manufacturing operations, many companies are looking at implementing key strategic technologies. Some notable key strategies are just-in-time (JIT), synchronous organization (SO), synchronous manufacturing (SM), etc. However, their impact on improving quality and reducing time-to-market has been mixed. Less success has been reported from their actual implementation than originally anticipated, compared to what the Japanese seem to have conquered using similar philosophies. Some of the strategic programmes have actually failed in the USA during their implementation stage, or at best can be said to have only reaped partial benefits[3,5,6]. It is not very clear why in some cases results were poor, when in a similar situation elsewhere, programmes have been proved to work well.

Problems associated with implementing JIT

Common factors that generally impede implementation of JIT programmes are constraints in human resources, planning and organizing, time and money. Im [3] reported the results of a survey on problems encountered by companies implementing JIT programmes. Based on Im[3] and other sources, the problems can be grouped into six categories:

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(1) *Improper or inadequate planning*. Manufacturing strategies are not like cook-books where one can follow a recipe and expect the results to be just fine. The needs and requirements of every company are different. If we apply a generic solution to all industry types, it is less likely that the returns on investment (ROI) will be optimal considering their usefulness. For example, there is no single best strategy to implement JIT. They are not made to a general specification as "one size fits all". For example, a line of JIT tactics initially identified for one company may not be applicable to a second company.

(2) *Changing market conditions*. The goals of a company frequently change with time and market conditions. A line of tactics that were chosen in one market condition or factory may not be valid in another. Depending on the market, business and factory (process) conditions at a particular point in time, a line of strategy and tactics should be dynamically designed and introduced. Mid-course corrections are necessary if the assumptions about company goals and market condition are no longer valid.

(3) *Competing tactics*. Many of the manufacturing strategies and tactics overlap each other. There are many possible sets of answers for the same set of requirements. The Venn diagram in Figure 1 shows an example of a typical overlap between a set of possible JIT tactics. There could be many situations like that when a set of JIT tactics is chosen for implementation. Suitability of chosen JIT tactics depends on the current production process, culture and many other factors that are in place. Thus, a line of JIT tactics initially identified at the start of a production process may not be valid later in the production process. Because of the competing nature, an updated set of tactics might be more appropriate and cost-effective later.

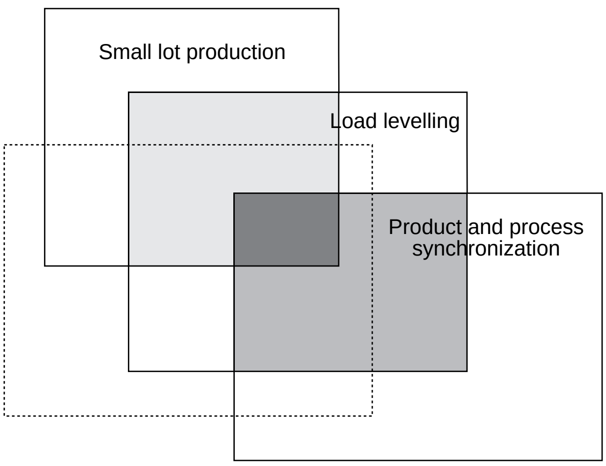

Figure 1.
JIT tactics – Venn diagram

(4) *Management problems*. This includes a lack of top management commitment, poor knowledge about techniques to be implemented, inadequate resources acquired in implementing the techniques, disorderly implementation, lack of employees' participation, lack of training and education.

(5) *Operation-related problems*. This includes unstable demand, and the variety of products. There are many operation-related problems to implementing JIT. These are[7]:
- problem with suppliers;
- need for production software;
- loss of control of inventory;
- inapplicability of JIT to low-volume operations or batch oriented productions;
- management complacency and fear of late production; and
- conflicts with ongoing projects

(6) *Process-related problems*. Such problems include long set up times, capacity imbalance between production stages, an inflexible workforce, and variable process times.

Most of the process-related problems can be solved by proper education and training. Some of the problems are not problems *per se* but represent the objectives of JIT (e.g. set-up time, quality improvement, etc.). To overcome these planning, management and process problems effectively, a custom design of a coherent programme (with systematic line of JIT tactics that best serve its purpose) is necessary. Companies interested in JIT look for flexibility in:

- Selecting their objectives that are based on their long term goals. They choose types of waste elimination options, productivity improvements and other system optimization objectives either based on their market position, competitive product offerings, or their customer preferences.
- Setting up programmes and the corresponding line of tactics in accordance with the needs of the company. Tactics are tailored to fit the custom design for a manufacturing environment in which they are expected to live and operate. Depending on a company's resource limitations or implementation constraints, management looks for flexibility in selecting a proper set of strategies that best serve one's needs and stated goals as discussed above.

Several EOQ (economic order quantity) approaches and multi-criterion optimization[7-12] have been applied to set-up time and lot size reduction problems and to multiple-products facility. Esrock[8] describes the impact of set-up time reduction on lot size, waiting time, lead time, etc. South[9] provides a basis for set-up time and lot size decisions in terms of given production capacity and multiple products. Miltenberg[10] and Miltenberg and Sinnamon[11] provide a theoretical basis of level scheduling of a mixed model JIT production system. Lee *et al.*[12] have developed a goal programming model for the lot size, set-up time reduction, inventory cost, demand, line-balancing, and scheduling problems to support management during decision making. Though the EOQ approach provides a theoretical foundation for analysing the conflicting JIT tactics, its application is impractical in production environment.

In this article, the author has found a way to classify JIT tactics by their characteristic parameters that govern their behaviour. A matrix-based structured approach has been proposed which can provide maximum cost benefits. With a structured methodology, a line of quality characteristics for a particular JIT strategy can be designed and developed which fulfils both tactical and strategic objectives.

Development of the JIT quality matrices

Before explaining the methodology of developing JIT quality matrices (JQM), it would be worthwhile to review the objectives of JIT.

The objectives of JIT

The philosophy of JIT aims at improving the productivity of the production system, for example[7,13-21]. Three types of objectives were earlier identified by Prasad[1] based on their significance in affecting manufacturing competitiveness. They are:

(1) performance improvement objectives (e.g. identification and elimination of waste);

(2) productivity improvement objectives; and

(3) operations and system control objectives.

The first set of objectives delineates waste components. Here, Ohno's[16] seven categories of waste were adopted. These improvements aim at eliminating, not just minimizing, waste arising in the production system. Thus, it is aimed towards increasing the productivity of the production system in the most fundamental ways. The second set of requirements matches each JIT technique to one of the five improvement objectives as reported by Prasad[1]. A third set of requirements identifies specific operations and system control objectives that need to be ensured through this strategy[4]. These objectives are measurable, fundamental, and intended to correct the root cause of the problems, not just their basic "symptoms".

House of JIT (HOJ)

The basic tool of JIT strategic planning is the "JIT quality matrix (JQM)". Matrices are popular methods of organizing information[17]. Matrices are schemata to define succinctly and relate directionally (like spread sheets) multiple lists of identifiers[22]. Figure 2 is a schematic view of a "House of JIT" matrix[1]. This house of JIT has eight rooms (matrices). Four of the matrices compose the basic perimeters of the house. These are lists of two "one-dimensional" (1-D) (row) matrices: [Whats] and [How-much], two 1-D (column) matrices: [Hows] and [Whys]. The House of JIT also encompasses relationships between these 1 -D (line) matrices resulting into four "two-dimensional (2-D) relational matrices": [Hows vs Hows]; [Whats vs Hows]; [Hows vs How-much]; and [Whats vs Whys]. Figure 3 identifies all matrices (1-D and 2-D) in the House of JIT (shown in Figure 2) by their popular names.

JIT quality matrices
JQM consists of eight fundamental matrices, all of which are relevant to analyse its impact on meeting a set of objectives as listed in a column called {Whats}. A full JIT Quality matrix (JQM) is shown in Figure 4.

Components of JQM
Figure 4 depicts the contents of each matrix, which gives us a glimpse of the full potential of the proposed structured methodology. There are four list-vectors which contain information on {Whats}, {Hows}, {Whys}, and {How-muches}, respectively. The {Whats} list contains the objectives a company would like to strive for from the point of view of implementing the manufacturing strategy. In the following section, we visit each metric of JQM and examine the essential features of JQM methodology.

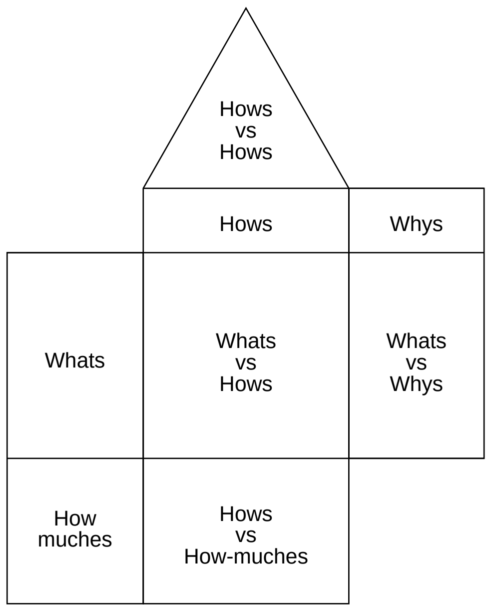

Figure 2.
House of JIT (HOJ)

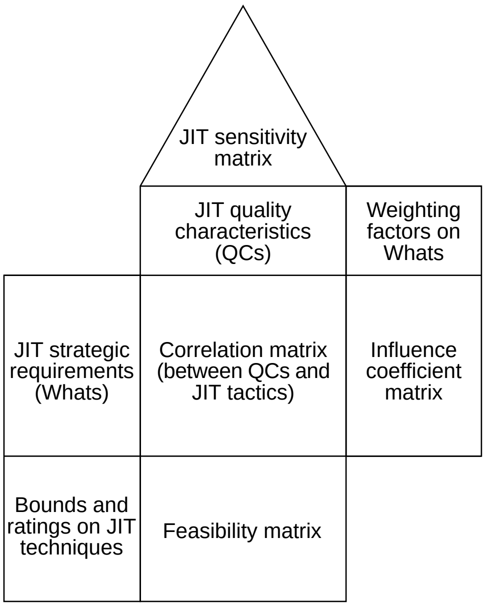

Figure 3.
HOJ list-vectors and matrices

JQM 1-D matrices

{Whats} list: JIT strategic requirements. {Whats}List of JQM contains a list of 17 JIT objectives. The rationale for their selection was discussed previously. The first set of objectives identifies the performance improvement objectives. This set shows seven types of waste to be eliminated based on Ohno[16]. The second set of five objectives shows the "productivity improvement objectives" to minimize or save resources (e.g. inventory space, time, labour, etc.). The third set of five objectives is aimed at improving the operations and system control elements. The last two sets are determined by the author[1], by reviewing the JIT literature on this subject and sorting out those objectives which carry distinct meanings.

The three types of objectives that a company generally strives to achieve:

(1) *Performance improvement objectives.* Here the objectives are focused on the ways to eliminate the so-called "three big problems – irrationality. inconsistency, and waste". The seven performance improvement objectives are chosen for this illustration waste of:
- information movements;
- overproduction;
- corrections;
- processing;
- inventory;
- waiting;
- motion.

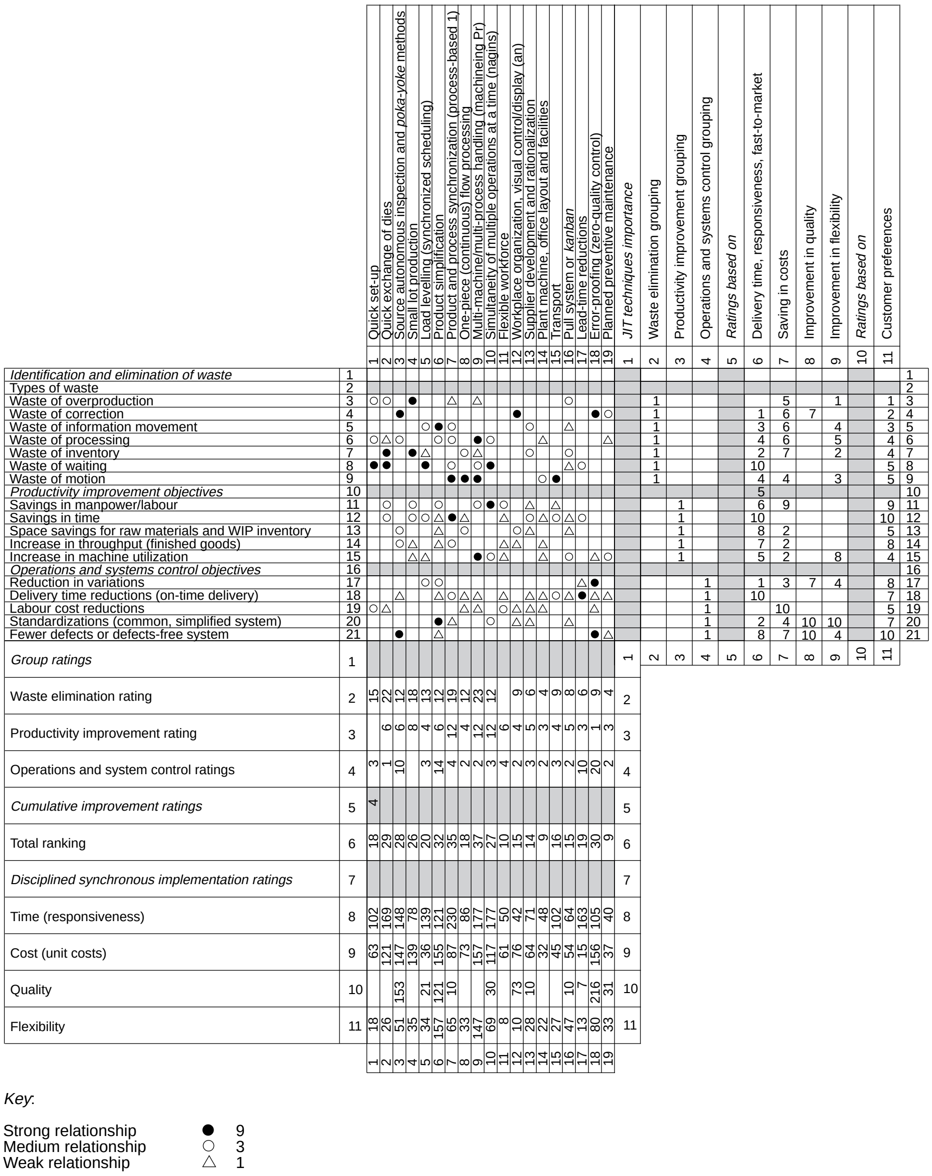

Figure 4.
JQM full house of matrices

The performance objective describes how much waste needs to be eliminated from the current process to measure up to the competitive benchmark (say, middle-of-the-road) targets.

(2) *Productivity improvement objectives*. These are "mid-term" objectives. They involve savings in resources and constraints providing "tangible" strategic gains to the company. The five productivity improvement objectives chosen for this illustration are:

- direct saving in manpower or labour;
- saving in time;
- less space for raw materials and work-in-progress inventory;
- higher throughput (or less space for finished goods);
- high machine utilization.

(3) *Operations and system control objectives*. These objectives are system level or long-term objectives. They involve doing several things at the same time so as to cause some incremental or intangible gains. The five operations and system control objectives chosen are:

- reduction in variations;
- delivery time reduction and on-time delivery;
- indirect labour cost reduction;
- fewer defects per part or defect free system;
- standardization (for example, common product and process, common system, open system architecture, etc.)

The aforementioned are some typical operations and systems objectives that most companies strive to attain. Like the performance objective set, this is not a complete list. Other objectives, that are operations or system type, may be categorized into one of the above five.

{Hows}: JIT quality characteristics items. Many JIT tactics have been developed and proposed in JIT environments. A list-vector in the JIT house, where tactics are listed, is called {Hows}(see Figure 5).

Some 220 articles and books on JIT were reviewed by Shin *et al.*[17] for identifying a matrix-based tool in assessing JIT's effect on the production system. In the present work, a set of 19 JIT tactics is chosen to form a Hows vector of this JQM matrix. There was no magic about choosing 19. This set happens to include a number of popular ones that we could find. Many of the same ones were used by Shin *et al.*[17] in developing a productivity improvement matrix. The tactics are drawn from what are considered to be the classics of JIT[4,15,16,18-20,23,24]. Others are based on the author's judgment gained through literature review (a partial list is contained in the references at the end of this article), consulting the manufacturing experts, and visits to "JlT implementing" plants in the USA. Key references include Inman and Mehra[5], Gilbert[6], and Im and Lee[3] and in Japan Shingo[18,19].

In the following passages, we list the tactics and some of the key items that are covered within each subject area:

- *Machine/job quick set-up*. Minimum set-up time between runs, multi-product and process capability.
- *Quick-exchange of dies*. The set-up and die changeover refers to the time lost between the production of the last item until the production of the

Whats vs. Hows		1 Quick set-up	2 Quick exchange of dies	3 Source autonomous inspection and *poka-yoke* methods	4 Small lot production	5 Load levelling (synchronized scheduling)	6 Product simplification	7 Product and process synchronization (process-based 1)	8 One-piece (continuous) flow processing	9 Multi-machine/multi-process handling (machineing Pr)	10 Simultaneity of multiple operations at a time (nagins)	11 Flexible workforce	12 Workplace organization, visual control/display (an)	13 Supplier development and rationalization	14 Plant machine, office layout and facilities	15 Transport	16 Pull system or *kanban*	17 Lead-time reductions	18 Error-proofing (zero-quality control)	19 Planned preventive maintenance	
Identification and elimination of waste	1																				1
Types of waste	2																				2
Waste of overproduction	3	○	○		●			△		△							○				3
Waste of corrections	4			●									●						●	○	4
Waste of information movement	5					○	●	○						○			△				5
Waste of processing	6	○	△	○			○	○		●	○				△					△	6
Waste of inventory	7		●		●	△			○	△				○			○				7
Waste of waiting	8	●	●			●		○		○	●						△	○			8
Waste of motion	9							●	●	●					○	●					9
Productivity improvement objectives	10																				10
Savings in manpower/labour	11		○		○		○			○	●	○		△		△					11
Savings in time	12		○		○	○	△	●	△			△		○	△	○	△	○			12
Space saving for raw materials and WIP inventory	13			○			△		○				○	△			△				13
Increase in throughput (finished goods)	14			○	△		△	○				△	△		△						14
Increase in machine utilization	15				△	△				●	○	△			△		○		△	○	15
Operations and systems control objectives	16																				16
Reduction in variations	17					○	○											△	●		17
Delivery time reductions (on-time delivery)	18			△			△	○	△	△		△		△	△	○	△	●	△	△	18
Labour cost reductions	19	○	△						△	△		○	△	△	△				△		19
Standardizations (common, simplified system)	20						●	△			○		△	△			△				20
Fewer defects or defects-free system	21			●			△												●	△	21

Key:
Strong relationship ● 9
Medium relationship ○ 3
Weak relationship △ 1

Figure 5.
JQM correlation matrix between company goals and JIT tactics [Whats vs Hows]

new item of comparable quality is made. The time includes teardown, rebuilding of the new process (exchange of dies), validation and inspection of the first pieces.

- *Source and autonomous inspection*. Source autonomous inspections and poka-yoke methods, measurements and inspection at the source of defects, use of sampling plans, automated data analysis and feedback.
- *Small lot production*. This consists of dividing overall production targets into small lots of parts. And within each lot, assigning system resources that maximize resource utilization. Prime among these are the tool capacity constraints that exist for each machine[25].

- *Load levelling (synchronized scheduling)*. Synchronous scheduling (or uniform plant loading) is a simple concept. It requires that one builds a single batch-size capability of what one would sell on a daily basis. Here, the rate of production is not tied to the machine rates, productive capacity, or sales forecasts. It is driven by sales orders (pull system) that cause production to flow from one operation to the next in the production sequence. That would result in manufacturing batch sizes that are small and consistent throughout the line.
- *Product simplification*. Companies that take the time to simplify processes – especially in the product design phase – before applying automated technology can maximize their return on investment. Product simplification brought about by quality function deployment (QFD) and continuous process improvements (CPI) often leads to parts cost reduction that can significantly outweigh the reductions brought in by individual methods, such as machine/job quick set-up costs, etc.
- *Product and process synchronization*. Ease of transfer into manufacturing, early manufacturing involvement, maximum process commonality, minimized rework, expedited feedback from process changes.
- *One-piece continuous flow processing*. The ability to produce a variety of parts through intelligent material handling devices.
- *Multi-machine/multi-process handling*. Capabilities allow allocations of parts and tools in a manner that maximize resource utilization. The capabilities balance the workload so that all machines finish their work for each batch more or less together (e.g. [25]).
- *Simultaneity of multiple operations at a time*. Automatic part screening, equipment utilization data collection.
- *Flexible workforce*. Cross training, alternate work schedules, minimal non-process steps for the operator. Use of a system that is user-friendly, adaptable or expandable.
- *Workplace organization, visual control/display*. This is equivalent to management by sight. Good visual/display system gives the warning prior to occurrence of problems as well as any corrective actions.
- *Supplier development and rationalization*. Use of goals and target dates, review processes, division of works, supplier involvement.
- *Plant machine, office layout and facilities*. Minimal transportation, flexibility, availability of parts and supplies. Workstation design with physical characteristics, lighting, noise, data entry and feedback.
- *Transportation*. Use of goods tracking system, consideration of transport batch size, backup strategies. Use of standardized carriers, minimal process handling, adaptation to future products.

- *Pull system or a* kanban. A pull system of production responds to customer orders immediately after an order is received. It is different from the push process which tries to move as much product as possible through the system, whether or not there are confirmed orders for the product.
- *Lead-time reductions*. Use of time analyses, value and non-value added analyses to determine waste and rework.
- *Error-proofing (zero-quality control)*. Use of control charts, process capability, minimal process variability, accessibility of data, decision algorithms' program.
- *Planned preventive maintenance*. Prevents disruptions in system operation. Examples of such disruptions are: machine failure, tool failure, tool replacement warning, material handling, system failures, etc.

  For each topic, the JIT matrix uses a consistent format for ranking, a set of common qualifiers, a set of Whys and How-much questions.

{How-muches}: bounds and ratings on JIT techniques. This is a user-defined vector-list and identifies the bounds or ratings (rankings) on the feasibility of Hows. These are also called How-muches and capture the extremes. Figure 6 lists a set of How-muches underneath the Hows.

{*Whys}: weighting factors on Whats.*: This is a vector-list which describes the relative importance of the current competitive production system – referred to as "world class" or "best of the class" plant/factory.

JQM 2-D (relational) matrices

[Whats vs Hows]: correlation matrix between objectives (company goals and customer wants) and JIT tactics. The most important matrix of JQM house of JIT is the correlation matrix that relates the objectives identified in {Whats} column with each of the 19 JIT techniques. JIT techniques appear as row of [Whats vs Hows] matrix (see Figure 5). This matrix correlates what a company desires in a manufacturing plant in terms of stated objectives together with how an enterprise can achieve those objectives. It is the core relational matrix of JQM. Relationship within [Whats vs Hows] matrix can be defined using a four-step measure:

(1) strong;

(2) medium;

(3) weak; or

(4) none.

An example is shown in Figure 5. This matrix may be densely populated (more than one row or column affected). This results from the fact that some of the JIT quality characteristics (QCs) affect more than one targeted objective. For example, what a company wants in "fewer defects or defect free system" or "waste in corrections" {Whats} are both affected by JIT tactics, such as "source or autonomous inspection", and poka-yoke methods, "error proofing", and "preventive maintenance" QCs (Hows). The more densely populated and spread

		JIT techniques importance	Waste elimination grouping	Productivity improvement grouping	Operation and systems control grouping	*Ratings based on*	Delivery time, responsiveness, fast-to-market	Saving in costs	Improvement in quality	Improvement in flexibility	*Ratings based on*	Customer preferences	
		1	2	3	4	5	6	7	8	9	10	11	
Identification and elimination of waste	1												1
Types of waste	2												2
Waste of overproduction	3		1					5		1		1	3
Waste of corrections	4		1				1	6	7			2	4
Waste of information movement	5		1				3	6		4		3	5
Waste of processing	6		1				4	6		5		4	6
Waste of inventory	7		1				2	7		2		4	7
Waste of waiting	8		1				10					5	8
Waste of motion	9		1				4	4		3		5	9
Productivity improvement objectives	10						5						10
Savings in manpower/labour	11			1			6	9				9	11
Savings in time	12			1			10					10	12
Space saving for raw materials and WIP inventory	13			1			8	2				5	13
Increase in throughput (finished goods)	14			1			7	2				8	14
Increase in machine utilization	15			1			5	2		8		4	15
Operations and systems control objectives	16												16
Reduction in variations	17				1		1	3	7	4		8	17
Delivery time reductions (on-time delivery)	18				1		10					7	18
Labour cost reductions	19				1			10				5	19
Standardizations (common, simplified system)	20				1		2	4	10	10		7	20
Fewer defects or defects-free system	21				1		8	7	10	4		10	21
		1	2	3	4	5	6	7	8	9	10	11	

Figure 6. JQM matrix of influence coefficients [Whats vs Whys]

in ranks the correlation matrix is, the more valuable such information is likely to be. A diagonal matrix means there are very little interactions between the JIT objectives (rows) and the JIT tactics (columns).

[*Whats vs Whys]: matrix of influence coefficients*. This is a weighting matrix. Weighting factors are used to prioritize the {Whats} (often referred to as customer/supplier weighting matrices; CWMs). This criterion for prioritization (CWM) forms the basis for selecting the right JIT strategies for a company. In the present application, the weighting data in the matrix (say a column) consist of the following (see Figure 6):

(1) JIT techniques group weighting. In this form of CWM usage – also called group weighting, CWM identifies the strategic importance of each of three Whats categories:

- waste elimination group weighting;
- productivity improvement group weighting;
- operations and systems control group weighting.

(2) Goal weighting. Weighting on how important different companies' management groups view each of the {What} with respect to accomplishing a particular goal. In this form, CWMs are categorized into four groups having weighting based on the following goals:
   - delivery time, responsiveness, and fast to-market;
   - savings in unit costs;
   - improvement in quality;
   - Improvement in flexibility.

(3) Weighting that a company management would like to impose on the specification of its plant or a JIT production system to match its capability with a "world-class level".

[Hows vs How-much]: this is also known as a feasibility of matrix for bounds and rating. Feasibility matrix lets one decide which of the JIT strategies or techniques {Hows} will have greatest or least impact on satisfying the JIT objectives {Whats}. The data in this matrix (say a row) is organized beneath the QCs matrix as shown in Figure 7.

[*Hows vs Hows]: this represents a self relationship between JIT tactics* {Hows}. This is described by a symmetric matrix (called sensitivity matrix) which forms the roof of the House of JIT (see Figure 8). The purpose of the roof is to identify the qualitative correlations among the 19 JIT tactics {Hows}.

Matrix-based procedure

The four-key relational matrices in the house of JIT (HOJ) discussed in the previous sections are seen in every QFD chart. They are basics of QFD methodology[26]. Many of these matrices are useful in drawing conclusions on the relative importance of {Whats}, {Whys}, {Hows} and so on. There are some computer programs and software which allow one to enter these matrices interactively. They also provide a variety of sorting and matrix analysis algorithms such as "weighted average", "ranking", "technical importance", "normalized ratings", "sum of {Whys} or {Hows} matrix column", "weighting factors", "weighting average", graphics utilities (bar charts, line chart, etc.) as reported by Prasad[26].

Before we show how JQM can be applied to solving a variety of problems, let us establish some nomenclatures for HOJ list-vectors and relational matrices. Let us denote the following:

HH: A sensitivity matrix defined by [Hows vs Hows].

WH: A correlation matrix defined by [Whats vs Hows].

WW: An influence matrix defined by [Whats vs Whys].

HM: A feasibility matrix defined by [Hows vs How-muches].

In the next section, we consider some optional features of a JQM chart.

		1 Quick set-up	2 Quick exchange of dies	3 Source autonomous inspection and *poka-yoke* methods	4 Small lot production	5 Load levelling (synchronized scheduling)	6 Product simplification	7 Product and process synchronization (process-based 1)	8 One-piece (continuous) flow processing	9 Multi-machine/multi-process handling (machineing Pr)	10 Simultaneity of multiple operations at a time (nagins)	11 Flexible workforce	12 Workplace organization, visual control/display (an)	13 Supplier development and rationalization	14 Plant machine, office layout and facilities	15 Transport	16 Pull system or *kanban*	17 Lead-time reductions	18 Error-proofing (zero-quality control)	19 Planned preventive maintenance	
Group ratings	1																				1
Waste elimination rating	2	15	22	12	18	13	12	19	12	23	12		9	6	4	9	8	6	9	4	2
Productivity improvement rating	3		6	6	8	4	6	12	4	12	12	6	4	5	3	4	5	3	1	3	3
Operations and systems control ratings	4	3	1	10		3	14	4	2	2	3	4	2	3	2	3	2	10	20	2	4
Cumulative improvement ratings	5																				5
Total ranking	6	18	29	28	26	20	32	35	18	37	27	10	15	14	9	16	15	19	30	9	6
Disciplined synchronous implementation ratings	7																				7
Time (responsiveness)	8	102	16	148	78	139	121	230	86	177	177	50	42	71	48	102	64	163	105	40	8
Cost (unit costs)	9	63	121	147	139	36	155	87	73	157	117	61	76	64	32	45	54	15	156	37	9
Quality	10			153		21	121	10			30		73	10			10	7	216	31	10
Flexibility	11	18	26	51	35	34	157	65	33	147	69	8	10	28	22	27	47	13	80	33	11
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	

Figure 7.
JQM: feasibility matrix of bounds on Hows (Hows vs How-much)

Weighting matrix comparisons

Weighting matrix comparisons are used in the JQM chart to weigh the competitor's JIT objectives with company objectives. There are two types of weighting matrices:

(1) *The competitor weighting matrix (CWM)* is developed by supplier/customer surveys (both external and internal) to weigh the suppliers'

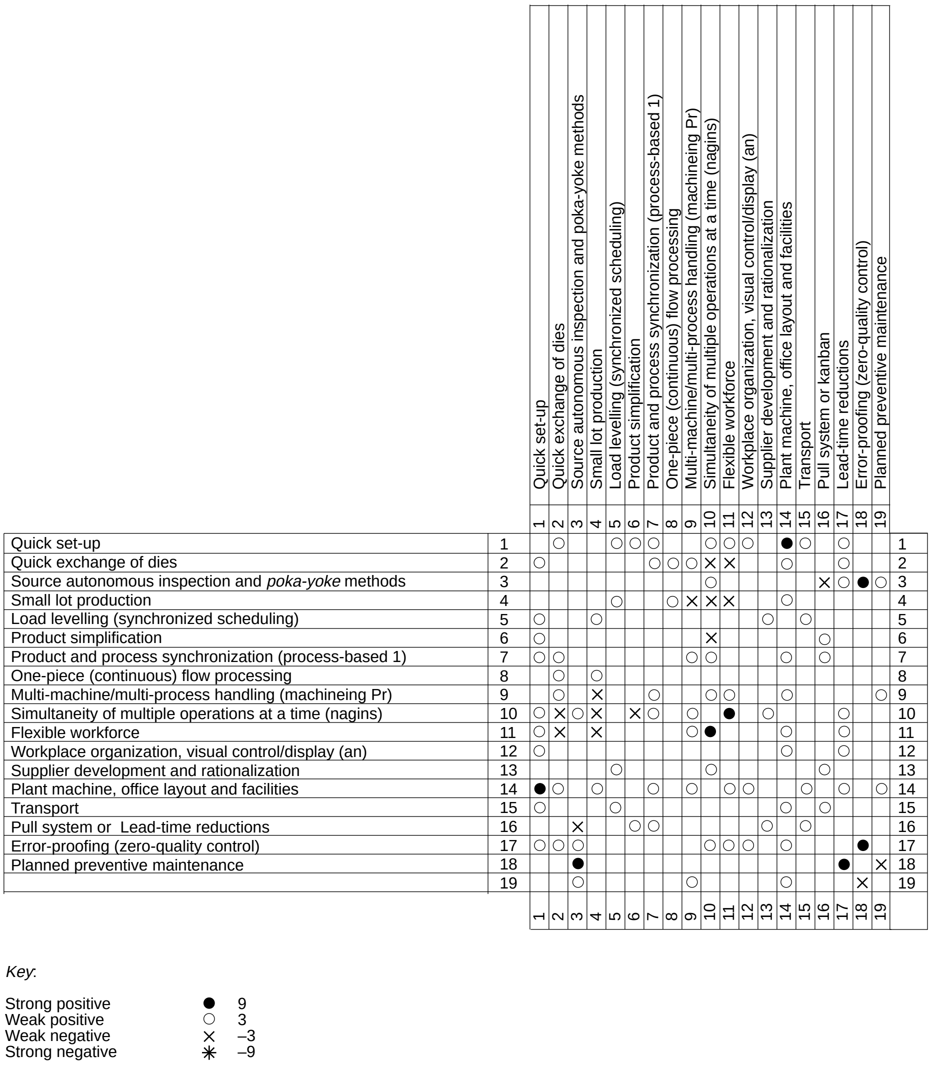

Figure 8.
JQM sensitivity matrix (Hows vs Hows)

opinion of the various JIT tactics in a particular industry sector. In the house of JIT, this is listed in [Whats vs Whys] relationship matrix. CWM weighs the Whats (perceived response). The [Whats vs Whys] column in Figure 7 contains the customer weighting matrix (CWM). JIT group weighting and goal weighting values are normally obtained through surveys.

By definition:

$$\mathrm{CWM} \equiv \mathrm{ww}_{ik} \tag{1}$$

where $i = 1, \ldots, n$; and $k = 1, \ldots, p$

(2) In a similar fashion, the {Hows} for the same competitor manufacturing establishments are weighed from a technical perspective. This second type of comparison is known as *technical weighting matrix* (TWM). In the house of JIT, this is found in [Hows vs How-muches] – relationship matrix. Technical assessments weigh the {Hows} (engineered or measured outputs).

By definition:

$$\text{TWM} \equiv hm_{lj} \tag{2}$$

where $j = 1, \ldots, m$; and $l = 1, \ldots, q$.

These two assessments are said to be in conflict when corresponding to a {What vs How} location (say wh_{ij}) there exists a strong positive {What vs Why} CWM value (say ww_{ik}), at the same time there exists a strong negative [Hows vs How-muches] TWM value (say hm_{lj}). In mathematical terms, a conflict occurs for an (i,j) combination, if there exists a row l in matrix HM and a column k in matrix WW, such that

$$\text{Limit } [ww_{ik} / hm_{lj}] \simeq 1; \tag{3}$$

corresponding to that (i, j) location.

Note a conflict occurs only when the ratio is close to a negative unity. For other values no conflict occurs. For example, if the ratio is a positive number, it represents a strong unity and existence of a good supporting data. Negative values far from –1 indicate existence of a discrepancy for that location in the correlation matrix. When the two (CWM and TWM) are in conflict, it often results from failure to understand the "voice of the customer/supplier". In such a case, the Hows list must be amended to reflect customer/supplier perception. This is most often resolved by letting process engineers directly get involved in the process assessments – comparing the in-house and the competitive manufacturing establishments.

Ratings comparison

Two types of importance ratings are commonly used in QFD as described by Prasad[26]:

(1) *Group importance ratings (GIRs)*. This examines the influence of a particular group of Whats on Hows. The 17 JIT objectives listed in {Whats} column are grouped into three distinct categories. In the section on Whats vs Why we have identified three sets of CWM values corresponding to these three groups. This has led into three group importance ratings (GIRs), namely, waste elimination GIR, productivity improvements GIR and operations and system control GIR.

(2) *Disciplined synchronous implementation ratings (DSIRs).* This examines the influence of all Whats on Hows in affecting a particular company goal. In the HOJ example we have listed four sets of CWM weighting

factors based on four separate goals. This has led into four DSIRs based on time, cost, quality and flexibility.

Both GIRs and DSIRs are the results of calculations from the HOJ matrix defined earlier. The steps used in the calculations of GIRs or DSIRs are as follows:

(1) Assign a numerical value for each symbol used in the correlation matrix (Whats vs Hows). A conversion table similar to what shown in Table 1 of Prasad[26] is most commonly employed.

(2) Corresponding to each What, multiply the [Whats vs Hows] equivalent numerical value of the correlation matrix by the [Whats vs Whys] CWM value.

(3) Repeat the results of multiplications in step (2) for all Whats and add the results in each Hows' column.

(4) Enter the results of step (3) into a [Hows vs How-muches] row. The row of computed numbers stored in [Hows vs How-muches] matrix represents GIR or DSIR for each How. If that row is a ith row of HM matrix, then, by definition,

$$\text{GIR or DSIR} \equiv hm_{lj} \equiv \sum_{j=1}^{m} [(\text{wh}_{ij})(\text{ww}_{ik})] \tag{4}$$

where, $i = 1, \ldots, n$; $j = 1, \ldots, m$;
$k = 1, \ldots, p$; and $l = 1, \ldots, q$;

Ratings, stored in lth row of [Hows vs How-muches] matrix, are a relative comparison of each jth element, provided the kth row contains the CWM value as shown by equation (1). Equation (4) represents an overall measurement of the group/implementation importance GIR or GSIR of the chosen JIT tactics.

Figure 7 illustrates the application of this concept for computing: group importance ratings (GIR) and disciplined synchronous implementation rating (DSIR). A typical correlation matrix [Whats vs Hows] may have symbolic representation. If so, they are first converted into quantitative value matrix using the conversions shown in Prasad[26, Table I]. These values are multiplied by the CWM value, resulting in an importance value for each location in the matrix. The JIT importance rating for each How is then found by adding together the computed values in each column. As an example, in the first column of the matrix in the Figure 5, the 3rd, 6th and 19th row – each has a value of 3 (= 1 × 3). The 8th row has a value of 9 (= 1 × 9). The group importance rating (GIR) for this column is thus the sum of the corresponding values in each group. For example in waste elimination group, GIR is 15 (9 + 3 + 3); productivity improvement group, GIR is Ø; and for operations and system control group, GIR Is 3. In HOJ, importance ratings (GIRs and DSIRs) are used to determine what JIT tactics should receive the most attention and are particularly useful in strategic trade-off decisions. The (GIR) is an example used to show the JIT prioritization process. Other factors might include:

- time (responsiveness);
- cost;
- quality;
- flexibility; etc. (see Figure 7).

A significant outcome and an important benefit of a successful JQM application is communication among all JIT planning and strategic team participants within an organization.

Though a general architecture for JQM matrices is presented, its individual implementation can differ depending on the company's objectives and priorities. The steps involved in the operating procedures are:

- *Step 1: identify problem areas*. The first step in the creation of a JQM matrix is to identify the problem areas as they relate to the production processes and operations. Is there any problem with long lead times, excessive inventory, underutilized equipments, or too many defective parts? These problems invariably identify particular types of JIT tactics which may be useful.
- *Step 2: identify the objectives*. Identify (add or delete from the basic Whats list) the right objectives based on the company's short-term and long-term goals. A list of 17 objectives is included in the JQM matrix. All may not be relevant for a particular company or in-house production process/capabilities.
- *Step 3: identify the JIT tactics*. Choose a set of JIT tactics that has better potential for improvements in strategic objectives. The entries in the Hows column in Figure 5 show the possible JIT candidates that can be chosen. This is typical of a list a particular company may be interested in. Note, however, that each company's needs are different. Their styles of management, contractual arrangements with hourly workforce, suppliers and cultures are all pivotal in determining the right mix of JIT tactics to consider at the outset. A JIT technique no matter what its potential may be, will do nobody any good if the company cannot exploit the resources to take advantage of its power. The list in Hows, thus, potentially serves as a useful list of JIT candidate techniques, which a company may choose. Note that the list is not exhaustive but quite representative in the light of the successes that have been achieved using them – as reported by Shin *et al.*[17]. Note many of the individual tactics can be broken down into specific subsets, if it better serves a company's interests. There are many variants of these tactics that are being used. It is not important, therefore, to choose a particular set, with which one is familiar with and which has worked well. Furthermore these tactics differ in the nature of their implementation.

- *Step 4: interview or survey the customers*. Within the frameworks of the programme management process, cross-functional teams are often employed to evaluate a production system for a new product in terms of the company's goals and principles. The team uses some measurement criteria in conducting evaluations during each phase of its product cycle and regularly thereafter during the manufacturing phase. In this article a two-step procedure is recommended:
  - Redefine the old (or initial) relationship matrix between the objectives and the tactics at the time of this evaluation.
  - Redefine the old priorities in accordance with the new company's objectives, its aligned policies, and changed market conditions.
- *Step 5: identify the JQM correlation matrix.* In this measurement system, relative score-points (in a scale of 0 to 10) are assigned (0 = weak to 10 = very strong) to the JQM matrix cells depending on the effectiveness of each JIT tactic in meeting the stated objectives. This is consistent with what initially proposed by Prasad[1]. Each member of the multidisciplinary team assigns a score-point value for each objective based on their best judgment. The evaluation team leader uses the individual rankings to come up with a single ranking value either through a mode of consensus or an averaging scheme. For the relationship matrix, the score-points are rounded to the nearest of the three ranking groups as follows: 7-10; strong; 4-6; medium and 0-3; weak. However, in the case of CWM weighting, the average score-point is entered for each What (JIT objective) in the {Whys} table. Each team member fills in a single sheet of JQM matrices. The team leader totals all the score-points and creates a matrix-sheet obtained through consensus or using methods of averaging. The results of individual evaluation sheets and the rationale to support the rankings are reviewed by management and discussed during scheduled programme reviews.
- *Step 6: set priorities on companies objectives*. The idea is to weigh the JIT objectives into achievable ranges in a scale of 0-10, or similar, thereby creating a priority table for the objectives. This information is often obtained through market survey and research.
- *Step 7: compute the importance ratings (GIRs and DSIRs).* This has been discussed in the previous section.
- *Step 8: play "What if" scenarios.* This is an important step in determining the right mix of JIT tactics that addresses the current set of problems, not the ones which existed four to six months ago.
- *Step 9: create the dependency matrix of JIT tactics.* This is an important feature that is contained in the roof of the JQM matrices. The importance arises from the fact that, at times, the specified JIT

techniques could be redundant and not add much value to the strategic goals while, at other times, they may be at opposed to each other. The [Hows vs Hows] sensitivity matrix of JQM helps identify the situations in such occurrences. If two Hows help each other in meeting the target values (listed in the [Hows vs How muches] row), they are rated as “positive” or “strongly positive”.Target value of a JIT tactic (How) is usually listed in the corresponding [Hows vs How-muches] feasibility matrix. If meeting one How target value makes it harder or impossible to meet another How target, those two Hows are rated as “negative,” or “strongly negative” relationships. Take for example the case of “one piece flow processing” and “multi-machine/multi-process handling” as two JIT items. Efforts to utilize the “one piece flow processing” technique would have an adverse effect on the “machine utilization”, even though capability may exist in the plant for “multi-machine/multi-process handling”. In this case, the two Hows thus have a negative correlation.

In actuality, correlations between JIT techniques could be positive or negative in varying degrees: strong, medium or none. When one How adversely affects another How, a qualitative negative correlation results; on the other hand, if it favourably supports the second How, a positive correlation results. For example, “loads levelling” and “pull system” are considered as having positive correlations because implementing load levelling will ease pull system, keeping all other remaining parameters constant. The weight symbols have been adapted here from quality function deployment (QFD) practices[26]. Symbols can be used to portray visually the different types of correlation.

- *Step 10: review JQM for accuracy.* After the JQM Is developed, care is taken in reviewing the matrices. Blank rows or columns call for closer scrutiny. A blank row implies a potential unsatisfied objective and emphasizes the need to develop one or more JIT tactics {Hows} for that particular objective {What}. A blank column implies that one of the JIT items does not directly relate to any of the JIT objectives. It may in turn emphasize a reallocation of resources or may point to a new objective that has not been identified.
- *Step 11: determine alternate strategies.* The final tally (matrix or a table of items) serves as a basis for determining the line of tactics suitable at a particular time during an implementation cycle. Depending on the results of the analyses, actions can be taken to stay on course or change the strategies in place. Action items may pertain to improvement in the product design, process definition, production system design, or manufacturing procedures depending on the areas of weaknesses. For instance, changes may be necessary in lot size, work scheduling, rework processes, production set-up, etc. This iterative

approach of evaluation, measurement, analysis and corrective action is expected to lead to continuous process improvement (CPI) throughout the production cycle.

It seemed appropriate to include a periodic review of JIT tactics as a part of company's existing practice of monitoring the introduction of new products into full scale manufacturing.

Application of JQM

In the foregoing discussion, a structured approach which is based on JQM is presented. The rationale for defining each room in the house of JIT (HOJ) matrix is explained. The full house of JIT is shown in Figure 4. The {Whats} column lists four group headings and 17 objectives (4 + 17 = 21 rows). The 17 objectives are for a company that may be interested in identifying the best JIT production system. The objectives include:

- seven provisions for waste elimination;
- five provisions for productivity improvements; and
- five provisions for operations and system control.

The results of the analysis are shown in the [Hows vs How-muches] columns. This information leads the teams to establish realistic goals (upper and lower bounds) for a line of JIT techniques. The rating mechanisms (GIRs and DSIRs) identify the strategic feasibility of applying one or more of JIT techniques. Depending on the GIRs or DSIRs a number of strategic paths (represented by rank order of the JIT tactics) are possible that would lead management to achieve its company's goals. This methodology can also be used to pinpoint where current technology is sufficient and/or where new manufacturing innovation is necessary. If a GIR or DSIR value for a JIT technique falls below a threshold, there is perhaps no need to spend resources in acquiring that particular technology. The others in the Hows list may do the job just fine.

Discussions

The whole idea of creating a series of JIT matrices is to provide company managers and strategic leaders with decision tools – to decide, on a dynamic basis, the best line of JIT tactics that may suit a company's changing priorities. JQM matrices, with JIT objectives identified along the Whats axis and a set of JIT quality characteristics (QCs) identified along the Hows axis, provide a sound rationale to determine a proper line of JIT tactics. JQM systematically guides managers to select the most appropriate set of JIT tactics according to the company's changing needs. The JQM initially serves as a guide (a decision- making tool) to custom design a set of JIT strategy in compliance with the company's resource constraints, market strategy, and supplier/customer expectations. It can also deal with trade-off evaluation and other circumstances encountered during a normal planning stage of manufacturing programmes. The JQM matrices provide managers with added flexibility to cope with anticipated problems and draw up an amicable JIT action plan for the changed situation if necessary. A JQM matrix also allows for weighting capability if two or more of the group ratings ought to be combined.

The most beneficial use of JQM is at the beginning of an actual JIT implementation. JQM helps the companies decide the best line of JIT tactics when companies are trying to implement lean manufacturing (JIT) programmes for the first time on an experimental or pilot basis. The normal JIT implementation process, however, takes one to two years to complete, during which people (employees, managers), suppliers and circumstances often change. The original line of tactics previously introduced may no longer be valid. Mid-course corrections are often necessary. Implementation of JIT during these times requires considerable care and an intense organized effort. The following are some specific ways JQM can be used:

- Guide decision makers in selecting the right JIT tactics for the situation at hand.
- Study and experiment various “what-if” scenarios before choosing a right mix of JIT tactics.
- Align planned implementation strategies with the company’s goals.
- Measure progress during implementation or pilot experimentation.
- Determine the change in course during various phases of JIT implementation, when some of the initial factors (economic, social or cultural) have changed. Meaning, they are no longer applicable from the last time it was planned. Such change in course may result from constraints in human resources, vacation schedules, time, money, or conflicts with other ongoing production schedules, labour disputes, etc.

At any point in its implementation, the structured approach contained herein helps to plan the best and the most reasonable alternate JIT programmes.

Strategic JIT scenarios

There are many JIT scenarios that one can study during Step 11. The following represents a subset that the author has found relevant for detailed discussion.

- *Scenario 1: determine the best JIT line of techniques that would have maximum impact on waste eliminations.* Row 2 in the [Hows vs How-muches] matrix (Figure 7) shows the results of waste eliminations. Among the 19 tactics being judged, quick exchange of dies, small lot production, product and process synchronization and multi-machine/multi-purpose handling tactics were found the most effective in the waste elimination category.

- *Scenario 2: determine the best JIT technique that would have maximum impact on productivity improvement*. Row 3 in the [Hows vs How-muches] matrix (Figure 7) shows the results for productivity improvements. Among the 19 techniques being judged, product and process synchronization, multi-machine/multi-purpose handling, and simultaneity of multiple operations at a time tactics were found the most effective in productivity improvement.
- *Scenario 3: determine the best JIT technique that would have maximum impact on operations and systems control improvements*. Row 4 in the [Hows vs How-muches] matrix shows the results. Among the 19 techniques being judged, source autonomous inspection and poka-yoke methods, product simplification, lead-time reduction and error-proofing (zero quality control) tactics were found the most effective in the operations and system control category.
- *Scenario 4: determine the best JIT technique that would have maximum impact on all identified objectives*. This is shown in rows 5-6 of the [Hows vs How-muches] matrix. A combined cumulative rating is obtained from the individual group ratings. One way to achieve this rating is by adding the individual ratings. This is the case, when all objectives are weighed equally. Among the 19 techniques being judged, error-proofing, product and process synchronization, multi-machine/multi-purpose handling and product simplification tactics are found the most effective.

The next five scenarios were targeted to utilize results from goal improvements ratings (DSIRs). Four management goals were set: delivery time (responsiveness), savings in costs, improvement in quality and improvement in flexibility. To obtain this ranking a qualified non-biased set of technical experts familiar with these JIT tactics were interviewed. They were asked to rank the importance of the 18 objectives as seen objectively. A brainstorming session was held and a consensus process emerged. The columns 6-9 of the [Whats vs Whys] matrix lists a consensus weighting. Note this weighting is a product/process or company dependent. Many factors and considerations went into identifying the weighting. The most common factors are: company culture, current practices, human factors, salaried vs hourly work force, training and education, availability of production equipments, etc. This list can be very long and most of the decisions are collectively made weighing most of the considerations that are relevant to the well being of the company.

- *Scenario 5: determine the best JIT technique that would have maximum impact on reducing the time-to-market aspect*. On the basis of the CWMs expressed in column 6 of [Whats vs Whys] matrix and the correlation matrix, a set of disciplined synchronous implementation ratings (DSIR) of the 19 JIT tactics was obtained. Column 8 of the

[Hows vs How-muches] matrix shows the results (computed DSIR values). Multimachine/multi-process handling, simultaneity of multiple operations at a time and lead-time reductions were found to be the most effective. Planned preventive maintenance, workplace organizations, and plant machine office layout were found to be the least effective of all JIT tactics in improving the time or responsiveness of the product's delivery.

- *Scenario 6: determine the best JIT technique that would have maximum impact on reducing the relative cost of production.* Column 7 of the [Whats vs Whys] matrix lists a consensus weighting for a management goal of savings in costs. The decisions are collectively made weighting most of the feasibility considerations that are relevant to the savings in costs. On the basis of the CWMs expressed in column 7 of the [Whats vs Whys] matrix and the correlation matrix, a set of DSlR ratings of the 19 JIT tactics was obtained. Column 9 of the [Hows vs How-muches] matrix shows the results (computed DSIR values). Multimachine/multi-process handling, error-proofing, product simplification, and source autonomous inspection and poka-yoke methods were found to be the most effective. lead-time reductions and plant machine office layout were found to be the least effective techniques among all JIT tactics for improving saving in costs.
- *Scenario 7: determine the best JIT technique that would have maximum impact on improving quality.* Column 8 of the [Whats vs Whys] matrix lists a consensus weighting for a management goal of improvements in quality. On the basis of the same JIT matrix, a DSIR of the 19 JIT tactics was obtained. Column 10 of the [Hows vs How-muches] matrix shows the results (computed DSIR values). Out of 19 JIT tactics adjudged, error-proofing and source autonomous inspection and poka-yoke methods were found to be the most effective as expected. Lead-time reductions and pull system or a *kanban* was found to be the least effective techniques for improving quality.
- *Scenario 8: determine the best JIT technique that would have maximum impact on improving flexibility of production*. Column 9 of the [Whats vs Whys] matrix lists a corresponding consensus weighting when the management goal is flexibility. Column 11 of [Hows vs How-muches] matrix shows the results (DSIR). Among the 19 tactics, "product simplification" and "multi-machine/multi-process handling" were found to be the most effective. Flexible workforce and workplace organization, visual control/displays were found to be the least effective techniques of all JIT for improving flexibility in production.
- *Scenario 9: determine the best JIT technique that would have maximum impact on a combination of the above four management*

factors: responsiveness, cost, quality or flexibility. A combined rating is obtained by calculating the mean of the individual DSIRs shown in rows 8-11. This gives a cumulative rating when all individual management criteria; time, cost, quality and flexibility are weighted equally. Among the 19 techniques judged, error-proofing, product and process synchronization, multi-machine/multi-purpose handling and product simplification tactics were found the most effective.

- *Scenario 10: determine the best JIT technique that would have maximum impact on improving the level of customer satisfaction.* Column 11 of the [Whats vs Whys] matrix list the "weights obtained from the voice of the customers". The table for customer preferences is generated through interviews or surveys. Customers who do not buy a company's product but may buy a competitive product, also have a voice. Furthermore, the "voice of the customer" should include inputs from in-house company sources such as manufacturing, purchasing, field support, service, suppliers, etc. They represent the company's internal customers. All three types of customers (buyers, non-buyers, and internal) and their satisfactions are important to characterize the stated goals. This makes the company goals more balanced and in line with the buyers. The results can be shown in a row of the [Hows vs How-muches] matrix, as in previous cases, creating the ratings based on customer preferences. This provides another perspective (decision angle) for the management. It provides for the management a perspective on how the customer perceives those JIT techniques. This is important because the customers would be the eventual users of the products manufactured through a production process possibly utilizing such tactics. How much this weighs against other considerations is up to the management to decide.
- *Scenario 11: determine the best line of JIT techniques when all five considerations are in force; however, management assigns different priorities for time (responsiveness), cost, quality, flexibility and customer satisfaction.* This means that the benefits are not equally weighted. As in previous cases, the result of this analysis can be computed and shown In a row of the [Hows vs How-muches] matrix. A typical weighting factor associated with each of the considerations: time (0.35); cost (0.25); quality (0.25), flexibility (0.10), and customer satisfaction (0.05) is usually prescribed. Please note, the numbers must add up to 1.0.

Conclusions

This study illustrates how implementation strategies (comprising of several JIT tactics, such as lot size, quick set-up, etc.) could be launched by applying JQM matrices. It also shows how various objectives can be incorporated into the decision matrices. The key features of this JQM can be summarized as follows.

First, JQM can accommodate multiple conflicting objectives of the JIT production philosophy and predict the right mix of JIT strategies to address various implementation issues. Use of the matrices helps to determine the critical JIT tactics and unify the manufacturing organizations with a set of common goals. Second, JQM can be applied to manufacturing situations where multiple products (in terms of product mix), multiple machines, and multiple processes exist on the factory floor.

Third, while JIT has become very popular among US manufacturers, the competing nature of some of its tactics leaves management with difficult dilemma of deciding on what is best for the company. The JQM matrix has been developed to measure how well a JIT implementation is working and should work, and to provide a vehicle for promoting and monitoring ongoing improvements. The methods can lead to timely delivery of quality products to the marketplace at a very competitive price.

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