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Empowerment of Factory's Cost Adaptability by TPM: A Strategic Direction of Japanese Manufacturers

Hiroshi Katayama

Waseda University, Department of Industrial and Management Systems Engineering
(kata@kata.mgmt.waseda.ac.jp)

Abstract

This paper discusses about redesign of firms' cost structure that have been considered by most Japanese manufacturers in this decade as one of the most urgent strategic direction. As a relevant tool for this subject, Total Productive Maintenance (TPM), a productivity improvement scheme born in Japan, have been utilised in many manufacturers and, recent years, the trend of its diversification among firms are remarkably accelerated. To understand the effectiveness of the TPM scheme, its advantageous feature for the subject and a successful case project is described.

1. Introduction

Before the ending of Japan's bubble economy, especially in 1970s and early 1980s, Japanese manufacturers had been trying to develop and enhance so-called 'lean production' [10] in terms of operation cost reduction. The purpose of this strategy was to win in the market by price competitiveness. This manufacturing concept had been realised mainly by KAIZEN movement and derivative facility investment. During middle of 1980s and early 1990s, investment for high-tech facilities and high performance indirect resources had been accelerated for adjusting the escalation of market volatility. These were flexible manufacturing systems, computer integrated manufacturing systems, information technologies for product design/development and skilled indirect human resources. In fact, quality of the products was considered to be the major factor to differentiate competitors among various strategic issues, *e.g.* cost, delivery, flexibility, service, and innovativeness. As a result, factory's cost structure at that period is characterised by high fixed cost and low variable cost. Most manufacturers did care nothing for their break-even points as sales were increasing rapidly beyond them.

The explosion of the bubble economy in early 1991 and continuing recession destroyed this environment. The relation between industry and market had suddenly changed from that of market-driven mass-customisation to supply-excessive business environment. Consequently, manufacturers have been forced to consider new behavioural scheme because their cost structure is no more profitable in this situation [21]. One relevant direction is to change such constitution from high fixed cost with low variable cost (high level flat cost structure) to low fixed cost with even higher variable cost (low level steeper cost structure). The latter cost structure is more risk-aversive in a current shrinking supply-excessive environment than the former, because its steep cost function makes actual manufacturing cost sensitive to the scale of demand. Therefore, this new strategic direction is called 'adaptable production' [11], [19].

Based on this idea, Japanese manufacturers are trying to shift their improvement target from variable cost reduction to fixed cost reduction in terms of asset rationalisation, labour resource outsourcing *etc*. One KAIZEN operations management scheme emphasising this direction is the Total Productive Maintenance (TPM) [5], [7], [8], [24], [25], [28], [34]. The feature of this scheme is characterised by cost reduction-focused improvement activity through loss definition and analysis. This scheme has been applied under its own award system for about 30 years and continues to contribute realisation of 'lean production'. Since the explosion of the bubble economy, number of applicant companies of this scheme has grown amazingly, *e.g.* 154 awarded business units including over 40 foreign companies in 1999. Main purpose of these activities is capability enhancement of various organisational aspects such as competitiveness on quality, cost, delivery *etc*. Furthermore, as a distinguished trend of recent TPM application, attempt of linking this scheme with manufacturing strategic consideration has been discussed among many industries [12], [17], [22], [29].

Based on these arguments, this paper discusses about how TPM procedure is effective for realisation of 'adaptable production'. Case studies of the proposed scheme carried out in actual TPM movements in some factories are also introduced, which guarantee its relevance.

2. A strategic direction

In this section, two concepts on production system are discussed for clarifying emerging manufacturers' strategic direction.

2.1 Basic concepts of production system

As described in the former section, lean production has been a basic but hidden concept among Japanese manufacturers, especially in Toyota group [23], before 1990. The aim of this concept is to realise efficient organisational constitution in terms of maximum output/input rate. To obtain this efficiency, Japanese firms have developed many distinguished management techniques and tools for long time and because of their organisational leanness, their way of manufacturing and organisations are called lean production (organisation).

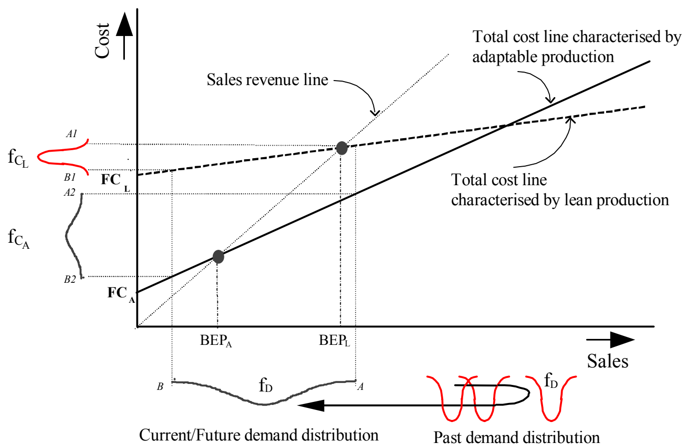
More concretely, the way to reach lean level is to make effort for input reduction with output encouragement. Where, input is not only materials but also every manufacturing resource such as labour, facilities, energy, training/skills and output is not only products themselves but also performance, quality and price of products, their environmental influence etc.

The incentive to cope with this issue is to stay at competitive edge in the ultimate competitive business environment and, as a result, companies have to respond the necessity to develop new products constantly and to acquire the facilities to produce them in the most resource-efficient manner. The constitution of lean production is, therefore, considered as offensive manufacturing and it has potentially generated the greater profit at the environment of higher levels of demand.

Adaptable production, on the other hand, is the concept to cope with the need to be reflected manufacturing cost to the rate of value addition, properly according to the demand fluctuation, which provide a reasonable business performance in the continuing shrunk market. This constitution potentially generates the reasonable profit at lower levels of demand and is considered as defensive manufacturing because it is robust against versatile and hanging low demand environment

2.2 Cost features of both production systems

The cost structures of these production concepts can be summarised in Table 1 [13] and graphical expression of the essence of these concept is given in Figure 1.



BEP_A	:Break-even point (BEP) of Adaptable production (AP)	f_{CA}	:Cost distribution of AP
		f_{CL}	:Cost distribution of LP
BEP_L	:BEP of lean production (LP)	FC_A	:Fixed cost of AP
f_D	:Demand distribution	FC_L	:Fixed cost of LP

Fig. 1 Cost Structures of Manufactures and their Adaptability to the Market

Table 1 Comparison of Cost Parameters of Lean and Adaptable Production

	Fixed cost	Variable cost	Break-even point	Cost sensitivity
Lean Production	**High**: High cost of fixed assets, indirect labour and indirect overheads	**Low**: Reduction in resource inputs and the drive for higher process performance	**High**:	**Low**:
Adaptable Production	**Low**: Equipment will not need to be replaced as frequently and its acquisition cost is likely to be lower since it would be more general purpose in nature	**High**: More manual work, greater inventories and use of less efficient equipment (although more flexible)	**Low**:	**High**:

3. Overview of the TPM scheme

In this section, fact data of international transfer of TPM scheme and the essential contents of this scheme is summarised for its evaluation as a transfer vehicle.

3.1 Diversifying TPM

Looking at the time series trend of the number of TPM award holders, the number of factories was very small before 1991 and has been gradually increased till the burst of Japan's bubble economy. However, after a few years, the number of factories became to exceed 150 sites in annual base. One major reason of this trend is that applicant manufacturers consider that TPM scheme is an effective method to survive in the sustaining tough business environment [4], [6], [30], [31], [33].

3.2 Basic elements of TPM scheme

In this section, the essential elements and factors of TPM scheme is summarised to avoid misunderstanding the role of this scheme. Roughly describing, TPM scheme consists of three elements, i.e. organisational aspects, focused issues for improvement and improvement technologies. Also, TPM scheme provides 6 levels of programme and each factory can start TPM from one of these different levels based on their historical background. In the following description, these three fundamental elements are summarised [9].

(1) 9 major pillars

The first issue, *i.e.* organisational aspect, is realised in terms of major pillars as the drivers of this improvement movement. The definition or explanation of each pillar is summarised in Table 2.

Table 2 TPM Pillars as Organisational Drivers

No.	TPM pillars	Explanation
1	Daily team maintenance	Daily maintenance activities by team members including operators
2	Focused improvement	Improvement projects for individual improvement topics
3	Planned maintenance	Maintenance system development and execution in consideration of breakdown, preventive and predictive maintenance
4	Quality maintenance	Root cause detection of off-quality for maintaining designed product quality
5	Early equipment management	Management of new equipment implementation for quick start-up
6	New product development	Management of new product development & implementation for fast response to the market
7	Continuous skills development	Skill identification & development through effective training and education
8	Office TPM	Reduction of indirect & administrative non-value added work for quick response
9	Safety and environment	Systematic elimination of potential safety & environmental incidents
	Other sector/total management	Creation of competitive edge, Augmentation of enterprise value

(2) Loss analysis

The second issue, i.e. focused issue for improvement, is loss analysis that is regarded as the philosophical basis of this scheme. The definition or explanation of each loss considered in TPM scheme is summarised in Table 3.

Table 3 Losses and their Definition

Loss class	Loss category	Definition
Traditional facility-oriented losses	Breakdowns	Unscheduled machine stops
	Change time	Time between the end and the next start of production run
	Fabric altering parts	Stops due to a deterioration/replacement of a machine part
	Start-up & shutdown	Time associated with stopping equipment and preparing the equipment for start-up
	Minor stop	Unscheduled machine stops that can be repaired by production associate
	Speed loss	Loss due to running equipment at actual speed lower than optimum production speed
	Defect & rework	The machine capacity that was consumed in additional efforts to correct products to the first quality
	Scheduled shutdown	Time lost due to planned stopping of machines for PM
	. . . .	. . . .
Management activity-base losses	Planning loss	Unscheduled machine stops due to not having the right material or information at the right place at the right time
	Training loss	Labour loss due to associates with less appropriate skills
	Over/Under manning loss	Losses that result from improper labour assignments
	Inspection & testing loss	Non-value added manpower related to inspecting & testing
	Waste loss	The difference between input volume of material and output volume of good quality product
	Obsolescence loss	Write downs due to closeouts, obsolete etc.
	Energy loss	Energy that continues even though machine is not producing
	Long life supplies loss	The cost of plant management supplies and change parts
	Discounts loss	Quality discounts, remnants and returns & allowances
	Return & allowances loss	Financial losses due to returned from customers
	. . . .	. . . .

(3) Tools

The third issue, i.e. improvement technologies, is the generic methodologies developed through the past TPM activities and contain in the TPM toolbox. The explanation of each tool is listed in Table 4 [26], [27], [32].

Table 4 Members of TPM Improvement Toolbox

Tool	Contents
PM analysis	Method to analyse the relation between failure phenomenon and resources
Why-why analysis	A search method of failure/defect cause
4M analysis	Method to establish the right condition of resources for right production
5S	Five important issues for factory, i.e. Seiri, Seiton Seisou, Seiketsu, Shitsuke
FMEA	Failure mode and effects analysis, an elemental technology of PM, which investigates statistical relation among failure modes and their effect on other systems to reduce the occurrence of actual failures
All other IE technologies	Motion-time study, Work measurement, Control chart, Statistical tests etc.
Process point analysis	Method of process failure elimination by focusing on the points that material is processed
Others	

4. A Case

In this section, a typical case of enhancement effort of cost adaptability [14] in semiconductor manufacturing factory is introduced for understanding its importance and way of approach.

4.1 Background

In the recent information-intensive society, semiconductors are becoming the kernel parts of industrial products, which continue to demand finer precision in processing than even the latest products due to technological innovation as well as customer needs (See Figure 3). As a result, the life cycle of memory chips is remarkably short, and shifting from the pilot production phase to the mass production phase can take from a few months to over a year (Figure 4 and 5). If it takes such a long time to realise mass production, instability during the transient duration causes loss and suppresses profit, and therefore proper initial phase management is considered as a key point.

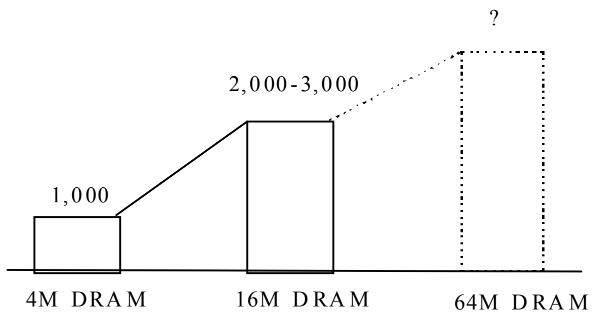


Fig. 3 Number of Chip Specifications

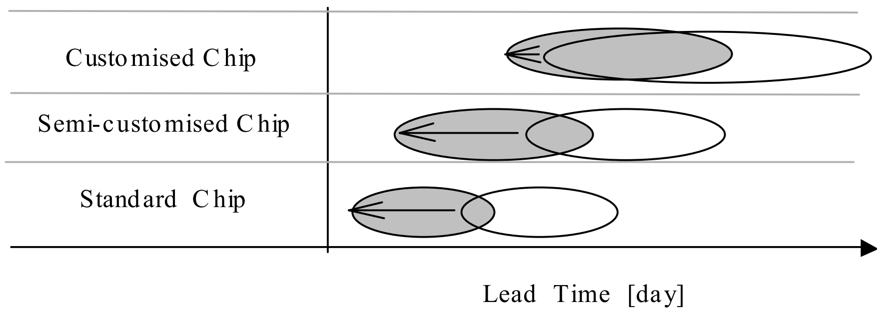


Fig. 4 Trend of Lead Time

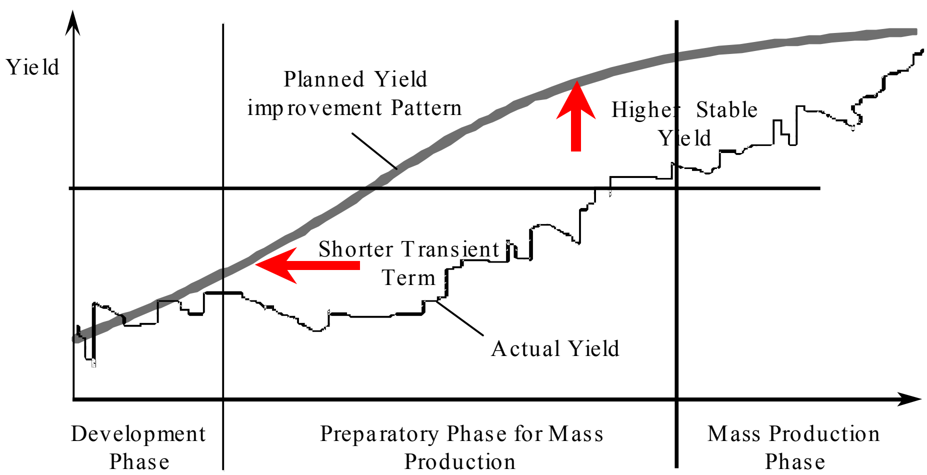


Fig. 5 Typical Pattern of Yield Rate and its Management

Looking at the global market of memory chip, on the other hand, its feature could be characterised by strong competitiveness due to joining major companies of matured as well as under developing industrial countries. Therefore, manufacturers have to offer shorter lead-time, lower defect rate, flexibility on product specification *etc.* to win in the market [1], [2], [3]. One of the relevant issue to contribute such aim is, as stressed by operations management professionals, structure of production management and its operational activities.

On the other hand, the precision of the equipment being used for semiconductor manufacture is, in general, not adequate for the precision required for products. Consequently, it is almost impossible to produce 100% certified products. In addition, it is next to impossible to repair rejected wafers because of large-scale high-precision products. This means that yield management for semiconductor products, which tries to improve the yield ratio and keep it stable, is one of the essential issues.

It is said that more than 80% of all defects are caused by adherence of particles on the wafer and the rough circuit patterns developed on it [15]. And the remarkable advances in high-precision processes in recent years promote further demands for finer patterns. As a result, much finer particles are starting to affect product yield, and the rate of defects caused by particles is tending to increase. Reduction of particles adherence on wafers is therefore regarded as one of the most effective policies to realise higher yields in semiconductor manufacturing. To cope with this trend and problem, manufacturers are forced to implement the latest high-tech. facilities and this constructs lean but non-adaptable cost constitution.

4.2 Manufacturing process

Hardware facilities of the manufacturing system and the workflow in it is illustrated in Figure 6 and 7, where genuine wafers are transformed to memory chip products through Process 1 (Diffusion/Particle Inspection), Process 2 (Metalisation/Probing Test) and Process 3 (Assembly).

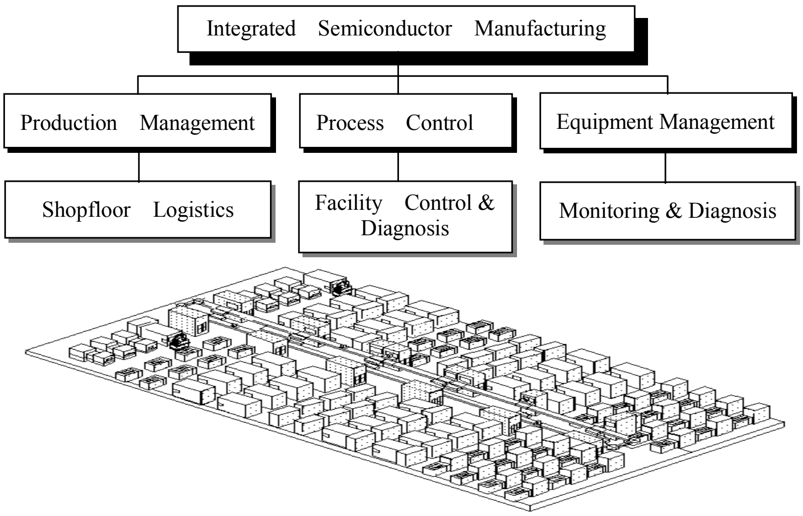


Fig. 6 Manufacturing System Overview (Bay System)

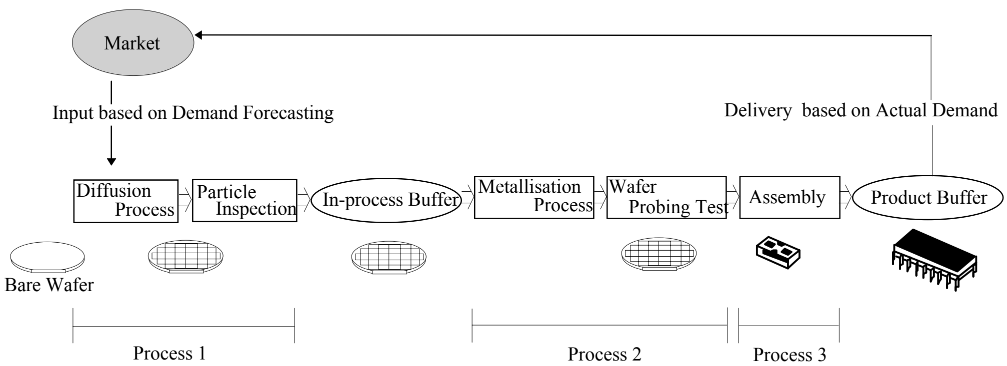


Fig. 7 Hardware and Workflow of Manufacturing System

4.3 Plant Profile

History of the case factory is summarised in Table 5 and the principal site feature is described as follows.

Table 5 Plant History

Fiscal Year	Events
19----	Foundation of the works
1974	Start of hybrid IC production
1978	Start of optical devices production
1980	Start of linear IC production
1983	Start of bipolar memory production
1985	Start of ASIC LSI production
1987	Start of MOS IC production
1988	Start of GaAs FET & IC production
1989	Establishment of semiconductor design & development centre
1997-8	TPM implementation and adaptability improvement

(1) Position in the company: The driving force factory of semiconductor & IC division BU
(2) Employees: NA
(3) Main products & variation: Memory -RAM, ROM-(10%), Linear IC (50%),
Logic IC (10%), Transistor (10%),
OPTO device (over 30% share in Japan), Hybrid IC
(4) Capacity (sales revenue) : Around $1,000,000,000 /year
(5) Investment: Around $2,000,000,000 /year
(6) Type of manufacturing system: Clean room automated manufacturing
(7) Customers: Home electronics manufacturers, OA manufacturers, main framer *etc*.
(8) Suppliers: Internal supplier + Group companies
(9) Emerging problems: 1) Customer Related Issues
-Ultimate competitiveness in the Market
-Volatile Demands
-Mismatching Demand-Supply Quantities
-Diverging Chip Specification
2) Operations Management Issues
-Low and Unstable Yield Rate in the Factory
-Requirement of Short Lead Time
-Shortage and Excess of Memory Chip Inventory
-Super Precision Manufacturing
-Huge Investments
-Growing Engineering to Order Manufacturing
3) Strategic Issue
-Necessity of Profitable Management System Construction
-Introduction of Clean Room CIM System

4.4 Efforts of Loss Reduction for Adaptable Production

To get a position of competitive edge in the narrow market through loss reduction activity, the case factory launched TPM movement. It was noticed from an initial investigation of loss mining and estimation that the major loss occurring in the clean room is defect of products, *i.e.* memory chips. Consequently, as an effective action programme, they decided to launch a new project that tries to develop "Clean Room CIM System" in the umbrella of TPM movement. The mission of this large-scale project is to provide adaptable production planning and control constitution for high variety low volume chip production [16] by monitoring each item's yield rate and work-in-progress inventories. The critical issues for success of the project are deployed as follows.

1) To improve cost adaptability of the factory, which is the key issue to survive in this industrial sector, it is necessary to reduce fixed cost even though increase of variable cost is allowed. It is also the duty to reduce product defect rate to sustain their competitiveness.
2) For the former problem in 1), *i.e.* improvement of cost adaptability, expensive facilities with low utilisation in each flow line process should be listed for TPM loss reduction targets. Then, proper improvement action programme for loss reduction should be carried out. However, in this case,

there is some danger of defect rate increase because flow type operation process itself contributes defect cause elimination. Simple flow type structure can significantly support detection of defect cause.

3) For the latter problem in 1), *i.e.* reduction of product defect rate, information processing system for defect mode analysis, defect process tracking and defect cause-effect analysis is necessary to develop and implement. This means some information technology-based infrastructure should be constructed.

Based on this consideration, they decided implementation of new job-shop type process into existing flow-type process lines with clean room information network infrastructure. The reason of this modification is to enhance process capability with improving facility utilisation rates and without sacrificing product yield rate. In fact, the facilities involved in the common job-shop that can provide variety of process functions have been operated with very low utilisation rates. Also, the new information network system for clean room, which is called clean room CIM, is expected to contribute defect cause analysis even in complicated job-shop environment.

Rough sketch of the layout of production facilities, which consist of mixture of conventional flow type lines and common job shops, is illustrated in Figure 8. This structure is obviously able to reduce redundant investment of expensive facilities.

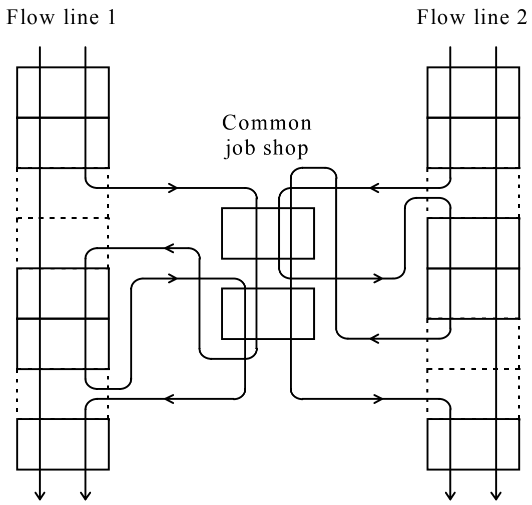


Fig. 8 Mixture of Flow Lines and Common Job Shop

4.5 Achievement

From this project settled under the umbrella of TPM movement, significant improvement of work man- hours for chip defect cause analysis was realised (See Figure 9). Also, substantial fixed cost reduction of super precision micro facilities was attained through implementation of common job-shop. Finally, quick response for yield management was provided by the new clean room CIM system.

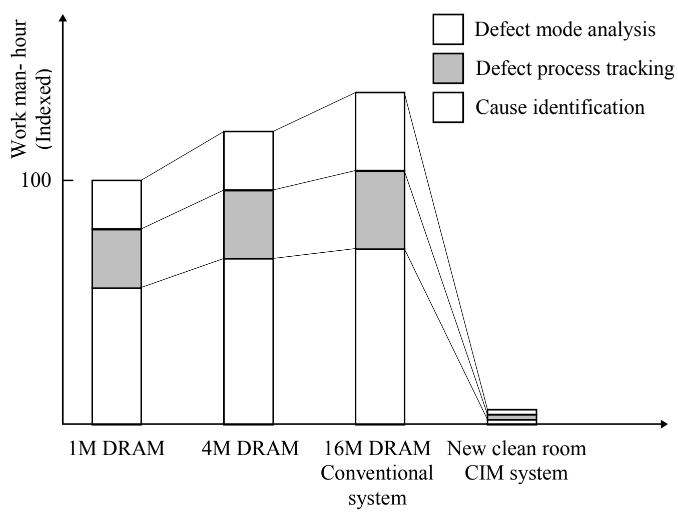


Fig. 9 Scale of Work Man-Hours for Defect Analysis

5. Concluding remarks

In this paper, direction of redesign Japanese manufacturer's cost structure, its rationality and a case problem solving performed by TPM implementation were discussed. Conventional break-even point analysis was utilised to figure out the right direction of firm's cost management, and the features of traditional Japanese way of production management, i.e. lean production, and a countermeasure direction, i.e. adaptable production, were described comparatively. Essential issues of TPM scheme, i.e. loss analysis, 9-pillar movement, improvement toolbox, were also described for understanding its relevancy. Then, a typical case of this tough problem was investigated. From the case study, it is suggest that TPM scheme is purely stand on the right logic for the subject, as its constitutional objective is elimination of losses, which are the major elements of cost. One effective way for further reinforcement of TPM to contribute redesign of firms' cost structure is development and implementation of new improvement technology. Possible new tools for this purpose are, for example, computer aided engineering (CAE) software for examining the way of improvement, the effective mechanisms of fail-safe/foolproof, project management software packages such as PERT, WBS for new product development and early equipment management, R & D management software tools such as TRIZ, Simulation software for evaluation of various corporate activities such as business process simulator, Company performance measurement software such as activity based costing (ABC) system, balanced scorecard etc. In these, ABC system will be the powerful support tool for TPM scheme as it provides more accurate cost data, which is critical for loss analysis, than conventional costing systems [18], [20]. Concerning to redesign of organisational cost structure, on the other hand, financial management and evaluation systems such as EVA and free cash flow reporting systems, which should include ABC system as a subsystem, will be the powerful support tools if proper action programmes are carried out based on these reporting systems. On this point of view, TPM is considered to be a relevant evolutional scheme. However, it must be strictly remarked that these tools are neither the objective nor the outcomes of the subject but the support tools for efficient and effective strategic cost management.

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