The Strategic Development of Advanced TPS based on a New Manufacturing Theory

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Abstract: - The Toyota Production System (TPS) exemplifies Japanese manufacturing though it has been further developed and spread in the form of internationally shared global production systems, including Just-in-Time (JIT). TPS is no longer a proprietary technology of Japan. This study focuses on the strategic development of Advanced TPS based on a new manufacturing theory through New JIT, a new management technology principle that surpasses conventional JIT practices. Specifically, the authors have developed the New Japan Global Production Model or NJ-GPM, a system designed to achieve worldwide uniform quality and production at optimal locations – which are the keys to successful global production. The effectiveness of NJ-GPM is demonstrated at Toyota, a leading international corporation.

Key-Words: - New Japan Global Production Model (NJ-GPM), Advanced TPS, Toyota

1 Introduction
The Japanese management technology that has contributed most to worldwide manufacturing since the second part of the 20th century is the Japanese Production System, which is typified by the Toyota Production System (TPS). TPS has been further developed and spread in the form of internationally shared global production systems such as Just-in-Time (JIT), and therefore it is no longer a proprietary technology of Japan. Digital engineering radically changes the way manufacturing is carried out at manufacturing sites. It is now necessary to re-construct Japan’s unique world-leading management technologies so that they will be viable even for the next generation of manufacturing.

With this in mind, this study focuses on the strategic development of “Advanced TPS.” It employs “New JIT,” a new management technology principle that surpasses conventional JIT practices [1-3]. The authors [4] have proposed a New Global Production Model (NJ-GPM) to enable the strategic development of Advanced TPS. The aim of this model is to realize a highly reliable production system suitable for global production by reviewing the production process from production planning and preparation through production itself and process management.

The core technologies that constitute NJ-GPM are: the TPS Layout Analysis System (TPS-LAS), the Human Intelligence - Production Operating System (HI-POS), the TPS Intelligent Production Operating System (TPS-IPOS), the TPS Quality Assurance System (TPS-QAS), the Human Digital Pipeline (HDP), and the Virtual - Maintenance Innovative Computer System (V-MICS). The model has proved to be effective at Toyota, a leading automobile manufacturer [4].

2 The Demand for Advances in Management Technology

2.1 Japanese Manufacturing: The History of JIT
The Japanese Production System is typified by the Toyota Production System (TPS) [5]. This system has been further developed as production systems known as JIT and Lean Systems [6-9]. The history of such development is shown in Figure 1 [2].

As seen in the diagram, Japanese manufacturing represented by TPS constitutes the basis for the manufacturing carried out worldwide today. Among the main management technologies that have contributed to the development of Japanese manufacturing are Industrial Engineering, Operations Research, Quality Control, Management, Marketing Research, Production Control, and Information Technology.

These are shown on the vertical axis of the diagram. On the horizontal axis, a variety of elemental technologies, management methods, and
Fig. 1 Progress of Management Technology in the Manufacturing Industry

Scientific methodologies are arranged in chronological order. Conventional Japanese manufacturing has developed from in-house production to cooperative relationships with suppliers, although management technology has become increasingly complicated.

Therefore, the current task of today’s manufacturing sector is to succeed in global production. A key to this is the development of supply chain management on a global scale that encompasses cooperative business operations even with overseas suppliers, and the ever-growing need for the systemization of such operation methods.

In particular, during the implementation stage the organically combined use of partnering, digital engineering (CAE, CAD, CAM), and Supply Chain Management (SCM) becomes necessary as they are essential for the development of the main components of JIT, namely, TPS and Total Quality Management (TQM). Therefore, in-depth study of the kind of management technology that will be effective even for next-generation business operations is also urgently needed.

In recent years, both developed Western nations and developing nations have advanced the study of Japanese TPS and TQM and acknowledged once again the importance of the quality of management technology. They have also promoted the reinforcement of quality in manufacturing on a national level [10]. As a result of such efforts, the superiority of Japanese product quality has rapidly diminished.

A typical example of this is seen in a comparison of the quality of automobiles sold in the United States. Although Toyota, still a leading Japanese car manufacturer, has achieved steady improvements in the quality of its automobiles (Initial Quality Study, or IQS) up until now, the American manufacturer GM and Korea’s Hyundai have also pushed quality improvements and achieved even more dramatic results [11].

These observations indicate that in order for Japanese manufacturers to continue to be global manufacturing leaders, they must reform their management technology from a fresh standpoint, rather than simply holding on to the successes of the past.

2.2 Toyota’s Management Technology - TPS and TQM

The system known as JIT, a Japanese production system typified by TPS, is a production system that was developed by Toyota Motor Corporation. This fundamental idea is the basic concept of JIT, which aims to realize quality and productivity simultaneously by effectively applying TQM to the automobile manufacturing process.

The system also pursues maximum rationalization (optimal streamlining, called a Lean System) to improve overall product quality while maintaining an awareness of the principles of cost reduction [1]. In the JIT implementation stage, it is important to constantly respond to customer needs, promote flawless production activities, and conduct timely QCD (Quality, Cost, and Delivery) research, as well as put it into practice.

Therefore, Toyota has positioned TPS and TQM as the core management technologies for realizing
“rational manufacturing” and these two management technologies are often likened to the two axles of an automobile. In Figure 2 these management technologies have been placed on the vertical and horizontal axes. As shown in the figure, the combination of these technologies reduces the large irregularities in manufacturing to tiny ripples, and average values are consistently improved in the process.

As indicated by the vertical and horizontal axes in the figure, when the hardware technology of TPS and the software technology of TQM are implemented, Statistical Quality Control (SQC) can be effectively incorporated to scientifically promote QCD research and achieve constant upgrading of manufacturing quality. The figure also reveals that TQM and SQC are the foundations for maintaining and improving manufacturing quality, and both have also historically served as a basis for the advancement of JIT.

2.3 Demand for a New Management Technologies that Surpass JIT
The environmental changes that surround today’s manufacturing industry are truly severe. It is vital for Japanese manufacturing not to fall behind in the advancement of management technologies. In order for manufacturers to succeed in the future world market, they need to continue to create products that will leave a strong impression on customers and to offer them in a timely fashion.

At present, TPS has been further developed and spread in the form of internationally shared global production systems such as JIT and the Lean System and is therefore no longer a proprietary technology of Japan. It is fair to say that what will ensure Japanese manufacturers’ success in global marketing is achieving competitive manufacturing (the simultaneous achievement of QCD) ahead of their competitors.

The urgent mission for Japanese manufacturers is to reconstruct world-leading, uniquely Japanese principles of management technology, which will be viable even for next-generation manufacturing [12]. In order to prevail in today’s competitive manufacturing industry, which is often referred to as a worldwide quality competition, the pressing management issue is to realize the kind of global production that can achieve so-called “worldwide uniform quality and production at optimal locations” [13].

3 The Strategic Development of “Advanced TPS” based on a “New Manufacturing Theory”

3.1 The Basic Principle of a “New Manufacturing Theory: Total Production System”
Given the situation described in the previous section, the authors have proposed the basic principle for a “New Manufacturing Theory”, which itself part of the evolutionary system of the Total Production System (TPS) as shown in Figure 3 [12-13].

This basic principle involves the core principles of “New JIT”, a new management technology established by the authors. New JIT consists of a Total Development System (shared use of information and optimized design technology creation), a Total Production System (achievement of highly reliable production), and a Total Marketing System (strengthening customer relationships and
incorporating reliability into products and corporate activities). As shown in the figure, the aim of this new manufacturing theory is to enable a focus on customers and employees as well as the reinforcement and improvement of process control through the incorporation of four sub-core elements (a through d).

The first element that must be deployed is production based on information (a). This means innovating the production management system so that it prioritizes quality information available both inside and outside of the company. It requires information on production philosophy in order to break free from the conventional practices. The second element is Production based on workplace configuration (b), which involves the creation of a rational production process and workplace configuration reforms in accordance with (a) above. The third element is production based on engineering (c), and this involves reinforcement of production technology through QCD research activities that utilize the latest production technology. Finally, production based on management (d) requires understanding the importance of human management and creating a highly creative and active workplace that utilizes and nurtures individuals’ innate abilities.

In order to achieve these aims it is necessary to strengthen the business process for production as a whole. For this purpose, it is extremely effective to strategically implement scientific quality management methods that apply “Science TQM” using “Science SQC”, which was also created by the authors [14-15].

3.2 Advanced TPS, Strategic Development Model of the Total Production System

Therefore, the authors [2-4, 16-17] have proposed “Advanced TPS” and the so-called “New Japan Production Model”, as introduced in Figure 4, in order to enable the strategic development of this new “Total Production System” manufacturing theory. The mission of Advanced TPS is to contribute to worldwide uniform quality and production at optimal locations as part of strategic development of global production and to attain Customer Satisfaction (CS), Employee Satisfaction (ES), and Social Satisfaction (SS) through manufacturing with a high level of quality assurance.

In terms of targets, this model is the systemization of a new, next-generation Japanese production management system for simultaneously achieving QCD requirements. Putting the model into practice will involve adapting it to handle digitalized production and reform it to realize an advanced production management system. Furthermore, other certain requirements, including the need to create an attractive working environments that can accommodate the increasing number of older and female workers at production sites and to cultivate operators that can handle intelligent production. These measures need to be organically combined in a positive cycle in order to make the simultaneous achievement of QCD possible.

One of the first technical element necessary for fulfilling these requirements is enhanced maintenance and improvement of process capabilities by establishing an intelligent quality control system. Second, a highly reliable production system needs to be established for high quality
assurance. Third, the working environment system needs to be reformed to enhance intelligent productivity. Fourth, intelligent production operators who are capable of handling the advanced production system need to be trained and developed. An intelligent production operating development system also needs to be established.

In order to offer customers high value-added products and win out in the worldwide quality competition, it is necessary to establish an advanced production system that can make production technology and production management systems more intelligent. This will in turn lead to high performance and highly functional new products. What determines the success of global production strategies is promoting technologies and skills that can fully utilize the above-mentioned advanced production system in order to achieve reliable manufacturing at production sites.

**4 Creation of the New Global Production Model “NJ-GPM”, Strategic Development of Advanced TPS**

Global production must be developed in order to establish the kind of manufacturing that is required to gain the trust of customers around the world by achieving a high level of quality assurance and efficiency, while shortening lead time. This will support the simultaneous achievement of QCD requirements. The vital key to achieving this is the introduction of a production system that incorporates production machinery automated with robots, skilled and experienced workers (production operators) to operate the machinery, and production information to organically combine them.

Thus, having recognized the need for a new production system suitable for global production, the authors [4] have created the New Global Production Model (NJ-GPM) shown in Figure 5 to realize the strategic development of “Advanced TPS”. This model eradicates ambiguities at each stage of the production process not only from production planning and preparation through production and process management, but also between these processes. The purpose is to achieve a highly reliable production system for global production that will improve the reliability of manufacturing through the clarification and complete coordination of these processes.

More specifically, the model is intended to (i) employ numerical simulation (Computer Aided Engineering, CAE) and computer graphics (CG) right from the production planning stage to resolve technical issues before they occur, (ii) reinforce production operators’ high-tech machine operating skills and manufacturing capabilities, and (iii) visualize the above using Information Technology.
in order to reform production information systems and create a global network of production sites.

The six core technologies that constitute this model and their characteristics are described below.

1. Reform of production planning: The TPS Layout Analysis System (TPS-LAS) is a production optimization system intended to create a highly reliable production system by optimizing the layout of both the production site as a whole and each production process with regard to production lines (logistics and transportation), robots (positioning), and production operators (allocation and workability) through the use of numeric simulation [18]. TPS-LAS is made up of four sub-systems: The Digital Factory CAE System (LAS-DFS), the Robot Control CAE System (LAS-RCS), the Workability Investigation CAE System (LAS-WIS), and the Logistic Investigation CAE System (LAS-LIS).

2. Reform of production preparation: The Human Intelligence–Production Operating System (HI-POS) is an intelligent operator development system intended to enable the establishment of a new people-oriented production system whereby training is conducted to ensure that operators develop the required skills to a uniform level. Thereafter, diagnosis is carried out to ensure that the right people are assigned to the right jobs [19]. HI-POS is made up of two sub-systems: The Human Integrated Assist System (HIA) and the Human Intelligence Diagnosis System (HID).

3. Reform of the working environment: The intelligent Production Operating System (TPS-IPOS) is intended to lead to a fundamental reform of the work involved in production operations by raising the technical skills level of production operators and further improving the reliability of their skills for operating advanced production equipment within an optimized working environment. TPS-IPOS is made up of three sub-systems: the Virtual–Intelligent Operator System (V-IOS) [20], the Aging & Work Development – Comfortable Operating System (AWD-COS) [21], and the Robot Reliability Design–Improvement Method (RRD-IM) [22].

4. Reform of process management: The TPS Quality Assurance System (TPS-QAS) is an integrated quality control system intended to ensure that quality is built into production processes through scientific process management that employs statistical science to secure process capability (Cp) and machine capability (Cm) [23]. TPS-QAS is made up of two sub-systems: the Quality Control Information System (QCIS), and the Availability & Reliability Information Monitor System (ARIM).

5. Visualization of production processes: The New Japan Global Production Model “NJ-GPM” (IT) is in Fig. 5 New Global Production Model, NJ-GPM
Human Digital Pipeline System (HDP) [24] ensures that top priority is given to customers by manufacturing with a high level of quality assurance. It involves the visualization of intelligent production information throughout product design, production planning and preparation, and production processes, thereby facilitating the complete coordination of these processes. This system enables a high-cyclization of business processes within manufacturing.

(6) Globalization of production information: The Virtual - Maintenance Innovated Computer System (V-MICS) [25] is a global network system for the systemization of the production management technology necessary to achieve a highly reliable production system, which in turn is required to achieve worldwide uniform quality and production at optimal locations. The newly-created NJ-GPM is fundamental to the strategic development of Advanced TPS. Through the operation of a dual system involving both V-MICS and HDP, this new model integrates the core technologies from production planning and preparation through working environments and process management.

In the next section, the authors verify the effectiveness of this research through some examples illustrating the development of NJ-GPM.

5 Example Applications
In this section, the authors [4] introduce some examples of research in Toyota’s pioneering technology as applications of the NJ-GPM, which has contributed to the advancement of management technology at Toyota.

5.1 TPS Layout Analysis System (TPS-LAS)
A simulation of main body conveyance using TPS-LAS (and its four constituent sub-systems) is shown in Figure 6 to illustrate a highly reliable production system that has contributed to the reform of production planning [18].

Firstly, the necessary production machinery is modeled, and a hypothetical production line is set up within a “digital factory” on a computer. TPS-LAS-DFS is then used to reproduce the flow of people and parts within the production site. This enables any interference between production machinery and production cycle times to be checked in advance using simulations. One type of advance simulation uses TPS-LAS-RCS for the optimum placement of welding robots for the main body to ensure that no interference occurs.

Next, advance verification is performed using TPS-LAS-WIS to ensure that the predetermined work (standardized work) is carried out within the...
predetermined cycle time with no waste (muda) or overburdening (muri). Then, TPS-LAS-LIS is used to establish optimized conveyance routes between processes and determine optimum buffer allocations.

TPS-LAS is currently being deployed as part of global production strategies, and is proving to be effective both in Japan and overseas.

5.2 Human Intelligence - Production Operating System (HI-POS)
The authors have implemented HI-POS by using its two constituent sub-systems – HID and HIA [19]. Figure 7 shows an example of a Total Link System Chart (TLSC) which represents the combined application of HID and HIA and illustrates the following points: (a) improved clarity and accuracy of analysis, (b) clearly structured production process evaluation criteria, (c) clearly indicated administrative links among organizations, (d) a bird’s-eye-view of work and information flows, (e) clarity of knowledge and know-how, (f) confirmation of available resources, and (g) issue detection and resolution.

A TLSC such as the one shown here is used to flush out any hidden problems. The problems found at various levels are clarified and categorized according to the KJ method [26]. Logical reasoning is applied to trace the root causes of the problems, and the appropriate evidence is gathered and organized. This is followed by the formulation and evaluation of counter-measures. Identified items (problems) are analyzed to evaluate the extent of improvement and the costs involved.

The use of the above systems and the TLSC used to represent them are currently being employed to promote proactive Kaizen (continuous improvements), which is proving to be effective both in Japan and overseas.

5.3 TPS Intelligent Production Operating System (TPS-IPOS)
The authors [23] are implementing the Intelligent Production Operating System (TPS-IPOS) by using three sub-systems.

Firstly, the Virtual - Intelligent Operator System (V-IOS) is intended to improve the skills of new (inexperienced) production operators both in Japan and overseas. For example, at special training centers with simulations of actual assembly lines as shown in Figure 8, both a) training processes for
assembly work, and b) work training systems for assembly work are employed in the training of operators.

Then, once a certain level of skills has been mastered, operators progress to actual assembly lines where they are promptly and methodically developed as highly skilled and experienced technicians using c) standard work sheets extracted from the aforementioned HID.

Secondly, the Aging & Work Development
Comfortable Operating System (AWD-COS) constitutes a fundamental reform of work and labor. Therefore, the authors [21] have initiated a company-wide project called Aging & Work Development 6 Programs Project (AWD6P/J) in order to combat the effects of aging, as shown in Figure 9. The programs involved are as follows: Program I is encouraging motivation in workers, Program II is reviewing working styles to reduce fatigue, Program III is creating physical strength through self-help efforts, Program IV is reducing heavy work with user-friendly tools and equipment, Program V is creating thermal environments suited to the characteristics of assembly work, and Program VI is reinforcing illness and injury prevention.

Thirdly, the Robot Reliability Design - Improvement Method (RRD-IM) is intended to improve the reliability of robots from development, production, introduction and operation, right up until they wear out and are replaced [23]. The body assembly line is a series model with multiple robots positioned as shown in Figure 10, and so the line’s availability is determined by the number of robots introduced.

Figure 11 shows a calculation used to obtain the relationship between the number of robots (N) and robot MTBF (t), where monthly operating hours (T) = 400 hours; significance level (α) = 0.05; failure repair time (r) = 1.2 hours; and the line’s required availability (A) = 98%. This shows that if 300 robots are introduced on a body assembly line, the necessary MTBF is 30,000 hours and, therefore, a ten-fold improvement is required in the existing robot MTBF of 3,000 hours.

The use of TPS-IPOS proves to be very effective at new factories overseas, for example, where the target operating efficiency (QCD effect and Safety) from start of production is being achieved at the same level and within the same timescales as factories in Japan.
5.4 TPS Quality Assurance System (TPS-QAS)
This system enables the development of manufacturing with superior quality and productivity by integrating two high-precision quality control systems suitable for global production [22].

Firstly, in order to analyze process management status in real time and enable diagnosis of process management abnormalities, the Quality Control Information System (QCIS) shown in Figure 12, automatically creates control charts using process analysis functions such as 1) the scroll function, the display of grouped and raw data, 3) innovative factorial analysis by layer, 4) a kaizen history database, 5) an abnormality diagnosis function, and 6) data links with other application software.

Secondly, the Availability & Reliability Information Monitor System (ARIM) gathers information on operating efficiency and failures for andon systems and clusters of machinery and equipment on each production line at factories in Japan and overseas as shown in Figure 13. This information is used to carry out a Weibull analysis of equipment failures and real time reliability analysis in order to maintain a high level of machine reliability and maintainability, thus enabling increased operational efficiency on production lines.

This TPS-QAS system enables fast and accurate process management on a global network, and it has been deployed with considerable effect.

5.5 Human Digital Pipeline (HDP)
The Human Digital Pipeline (HDP) shown in Figure 14 has the following features [24]: First HDP creates and supplies in advance “Standard Work Sheets” on which production operators have recorded each task in the correct order for jobs such as assembly work. The sheets use design data for new products and facilities prepared from design through to production technology, even if there are no production prototypes. Next, HDP enables visualization training for machining processes step-by-step in the order that parts are built up, even if the actual product does not yet exist. The system is proving to be very effective in raising the level of proficiency for processes requiring skills and capabilities at the production preparation stage.

5.6 Virtual - Maintenance Innovated Computer System (V-MICS)
The Virtual-Maintenance Innovated Computer System (V-MICS) shown in Figure 15 takes a server and client system configuration, with a server specially set up for each production site [25]. Production operators are able to browse information using databases (DB) and computer graphics (CG) whenever necessary from the client computers at each maintenance station via the network, and can
also input any special items as necessary.

Also, the servers at each site are synchronized with the central server (V-MICS server) so that any new information is simultaneously recorded and sent out to each server. This enables knowledge and information for each process to be shared and experienced virtually on computers among sites within and outside of different countries.

Coordination with the aforementioned TPS-LAS, HI-POS, TPS-IPOS, TPS-QAS, and HDP has enabled the strategic operation of a global production system with considerable effect.

6 CONCLUSION

In order to re-construct the principles of management technology and Japan’s unique world-leading management technologies so that they will be viable even for the next generation of manufacturing, the authors have also created a “New Global Production Model, NJ-GPM” to enable the strategic development of Advanced TPS, and its effectiveness has been verified at Toyota.

Today, the creation of new manufacturing models must drive a significant leap forward in Japanese-style manufacturing fundamentals. The authors’ new model, NJ-GPM, can serve as just such a global model. At present, the new model is undergoing a verification process to prove its validity at many other advanced Japanese companies [3, 12-13].

Appendix A: Research Methodology for Deriving the Framework of “NJ-GPM”

The key to the research methodology used to derive the framework of "NJ-GPM" is the reform of Japanese production processes to contribute to the advancement of manufacturing through QCD research [12-13, 16]. The following main points are important in studying such reform toward global production.

(1) The fundamental principle of JIT production is “manufacturing only what can be sold, when it can be sold, in the quantity that can be sold.” The rational production measure required to accomplish this is the establishment of a flexible production system that will “produce and transport only what is needed, when it is needed, in the quantity that is needed.”

(2) In order to achieve the conditions listed above it is important to carry out comprehensive production planning utilizing Computer Aided Engineering (CAE) and Computer Graphics (CG) so that production leveling, shortening of the production lead time, and a pull system are thoroughly incorporated into the planning and design of processes.

(3) Process improvements must be made to create a production layout that facilitates the incorporation of quality by implementing countermeasures for the “outlying island” layout. This makes it possible to improve production operating efficiency, stabilize
quality, and enable flexible production in response to changes in production levels.

(4) The logical way to do this is to use signboards, facilitate small batch conveyance to boost precision, promote the flow of the production process, and determine the takt time according to the required volume.

(5) In recent years, it is becoming increasingly important to improve product quality in response to rising customer expectations. It is therefore imperative to develop and introduce automatic inspection devices to conduct the quantitative evaluation of bottleneck-causing work (work that require intuition and know-how) and carry out fault diagnoses.

(6) It is also imperative to reinforce the production site as a whole on a fundamental level and to advance JIT production by actively developing new production technologies that eradicate the technological problems that cause bottlenecks in production, thereby substantially improving quality and productivity.

(7) From the viewpoint of global production, production engineering and manufacturing divisions are expected to achieve high-level quality assurance and productivity. This involves factors such as the use of digital engineering, planning and implementation of intelligent production systems, operations and maintenance skills, the evolution of manufacturing skills and training, and innovations to make the work environment more eco-friendly.

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