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Development of *Advanced TPS*

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Review of the New Japan Global Production Model “NJ-GPM”:

Strategic Development of *Advanced TPS*

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Abstract: The Toyota Production System (TPS) exemplifies Japanese manufacturing, though it has since been further developed and spread in the form of internationally shared global production systems, including Just in Time (JIT). As a result, TPS is no longer a proprietary technology of Japan. This study focuses on the strategic deployment of *Advanced TPS* through *New JIT*, an innovative management technology principle that surpasses conventional JIT practices. Specifically, the author develops the New Japan Global Production Model “NJ-GPM”, a system designed to achieve worldwide uniform quality and production at optimal locations—keys to successful global production. The effectiveness of NJ-GPM is demonstrated at Toyota, a leading international corporation.

Keywords: New Japan Global Production Model “NJ-GPM”, *Advanced TPS*, *New JIT*, Toyota

1. Introduction

The leading Japanese administrative management technology that contributed most to worldwide manufacturing from the second half of the 20th century was the Japanese Production System, which is typified by the Toyota Production System (TPS). However, 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 is bringing about radical changes in the way manufacturing is carried out at manufacturing sites. This means that it is now necessary to re-construct the principles of management technology and Japan's unique world-leading administrative 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 deployment of "*Advanced TPS*" employing "*New JIT*" [1-3], an innovative management technology principle that surpasses conventional JIT practices. Specifically, the author has proposed a New Global Production Model (NJ-GPM) to enable the strategic deployment 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 the model are TPS Layout Analysis System (TPS-LAS), Human Intelligence - Production Operating System (HI-POS), TPS Intelligent Production Operating System (TPS-IPOS), TPS Quality Assurance System (TPS-QAS), Human Digital Pipeline (HDP), and Virtual - Maintenance Innovated Computer System (V-MICS). The model has proved to be effective at Toyota, a leading automobile manufacturer.

2. The Demand for Advances in Administrative Management Technology

2.1 Japanese Manufacturing - The History of JIT

The leading Japanese administrative management technology that contributed most to worldwide manufacturing from the second half of the 20th century was the Japanese Production System. This is typified by the Toyota Production System (TPS) [4]. This system has been further developed as production systems known as Just in Time (JIT) and Lean Systems [5-8]. The history of such development is shown in Fig. 1, “Transition in Management Technology” [2,3].

As seen in the diagram, the Japanese manufacturing represented by TPS constitutes the basis for the manufacturing carried out worldwide today. Among the main administrative management technologies that have contributed to the development of Japanese manufacturing are Industrial Engineering, Operations Research, Quality Control, Administrative 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 scientific methodologies are arranged in chronological order. Conventional Japanese manufacturing has developed from in-house production to cooperative relationships with suppliers although, since the beginning

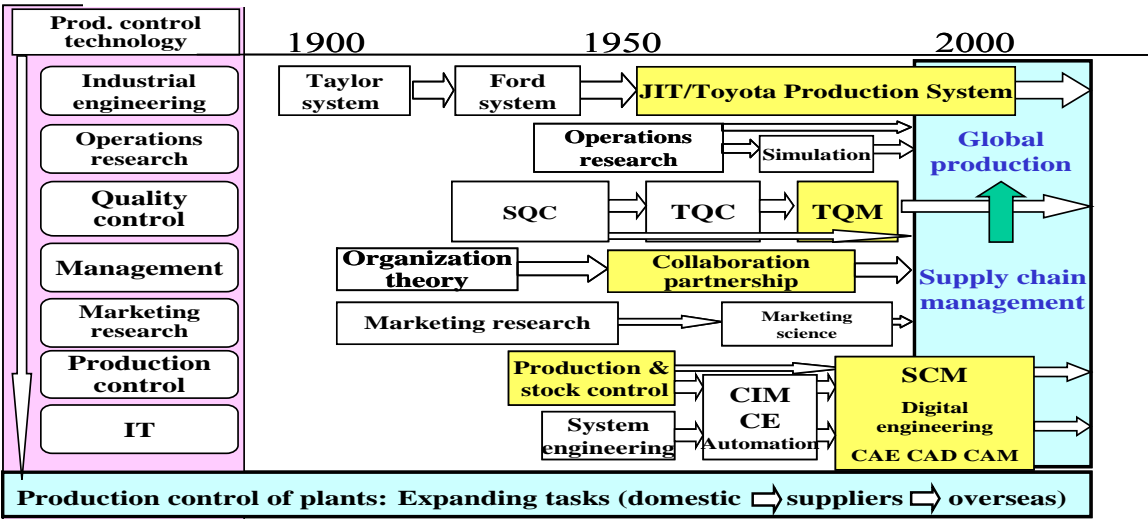


Fig. 1 Progress of Management Technology in the Manufacturing Industry

administrative 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 deployment 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 and digital engineering (CAE, CAD, CAM), and Supply Chain Management (SCM) will become necessary as they are essential for the deployment of the main components of JIT, namely, TPS and Total Quality Management (TQM). Therefore, in-depth study of the kind of administrative management technology that will be effective even for next-generation business operations is also urgently needed.

In recent years, however, both developed Western nations and developing nations have advanced the study of Japanese TPS and TQM and re-acknowledged the importance of the quality of administrative management technology. They have also promoted the reinforcement of quality in manufacturing on a national level [9]. As a result of such efforts, the superior quality of Japanese products has been rapidly compromised. One distinctive example of this is shown in a comparison of the quality of automobiles sold in the United States. Although Toyota, still a leading Japanese car manufacturer, can be seen to have achieved steady improvements in the quality of its automobiles (IQS, Initial Quality Study) up to now, GM of the United States and Hyundai of Korea have also promoted quality improvements and achieved even more dramatic results [9]. The observations above indicate that in order for Japanese manufacturers to continue to play the leading role in the world, it is urgent to reform their administrative management technology from a fresh standpoint, rather than simply clinging to the successful experiences they have enjoyed up to now.

2.2 Toyota’s Management Technology - TPS and TQM

The system known as Just In Time (JIT), a Japanese production system typified by the TPS, is a production system that was developed by the Toyota Motor Corporation. These fundamental ideas are the basic concepts of JIT, which aims to realize quality and productivity simultaneously by effectively applying TQM to the automobile manufacturing process. The system also pursues maximum efficiency (optimal streamlining, which is called a Lean System) while also being conscious of the principles of cost reduction, and thereby improving overall product quality [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 management technologies are often likened to being the wheels of an automobile. In Fig. 2 these management technologies have been placed on the vertical and horizontal axes. As shown in the figure, the combination of these technologies reduces large irregularities in manufacturing to the state of tiny ripples where the average values are consistently improved in the process. As indicated by the vertical and horizontal axes in the figure, when the hardware technology of the TPS and the software technology of TQM are implemented, Statistical Quality Control (SQC) is to be effectively incorporated to scientifically promote QCD research and achieve constant upgrading of the manufacturing quality. Another point that can be understood from the figure is that TQM and SQC are the foundations of maintaining and improving the manufacturing quality, and both have also historically served as a basis for the

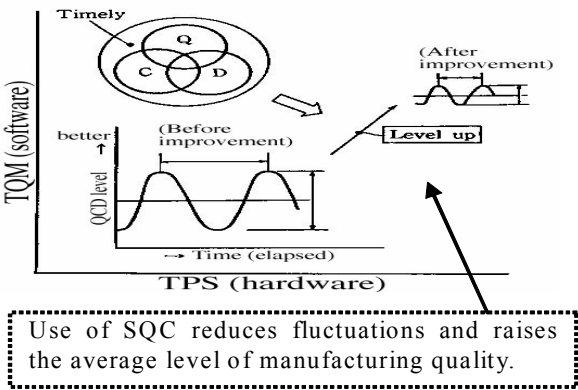


Fig. 2 Toyota’s Management Technology - TPS and TQM

advancement of JIT.

2.3 Demand for a New Management Technologies that Surpasses 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 a manufacturer to succeed in the future world market, it needs to continue to create products that will leave a strong impression on customers and to offer them in a timely fashion. At present however, the TPS, which is representative of Japanese manufacturing, has been further developed and spread in the form of internationally shared global production systems such as JIT and the Lean System and therefore it is no longer a proprietary technology of Japan.

It is not an exaggeration to say that what will ensure Japanese manufacturers' success in global marketing is the realization of 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 and administrative management technology, which will be viable even for next-generation manufacturing [11].

The environmental changes that surround today's manufacturing industry are truly severe. 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 the so-called “worldwide uniform quality and simultaneous production (production at optimal locations)” [12].

3. The Strategic Deployment of “Advanced TPS” based on the “New Manufacturing Theory

3.1 The Basic Principle of the “New Manufacturing Theory- Total Production System”

Given this background, the author has proposed the basic principle for the “New Manufacturing Theory” that is positioned as part of the evolution system of TPS “Total Production System” as shown in Fig. 3 [2,3,11,12]. This basic principle entails the core principles of “New JIT”,

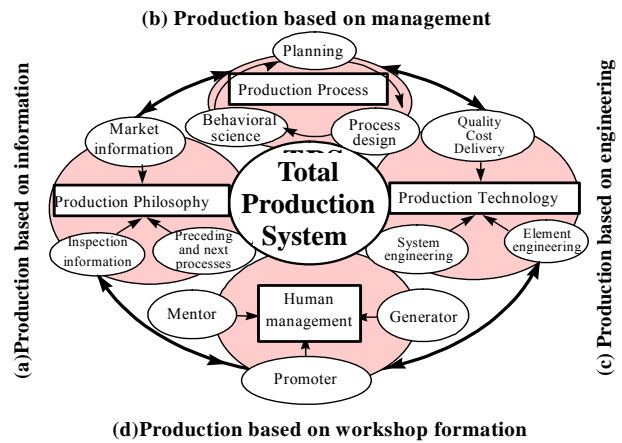


Fig. 3 Total Production System

the next-generation management technology established by the author: Total Development System, Total Production System, and Total Marketing System.

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 incorporation of four sub core elements (a to d). The first element that must be deployed is (a) production based on information. This means innovation of the production management system that gives priority to quality information available both inside and outside of the company. This requires reformation of the production philosophy in order to break free from the conventional practices. Production based on workplace configuration (b) entails the creation of a rational production process and reform of the workplace configuration in accordance with this. Production based on technology (c) 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 which 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 applying “Science TQM” by using “Science SQC”,

which was established by the author [13,14].

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

Therefore, the author [2,3,12] has proposed the “Advanced TPS” so-called “New Japan Production Model”, as introduced in Fig. 4, in order to enable the strategic deployment of this new manufacturing theory “Total Production System”. The mission of *Advanced TPS* is to contribute to worldwide uniform quality and simultaneous launch (production at optimal locations) as a strategic deployment of global production and to realize Customer Satisfaction (CS), Employee Satisfaction (ES), and Social Satisfaction (SS) through high quality assurance manufacturing.

On a concrete target, this model is the systemization of a new, next-generation Japanese production management system and this involves the high-cyclization of the production process for realizing the simultaneous achievement of QCD requirements. In order to make this model into a reality it will be necessary to adapt it to handle digitalized production and reform it to realize an advanced production management system. Furthermore, other prerequisites for realizing this include the need to create an attractive working environment that can accommodate the increasing number of older and female workers at the production

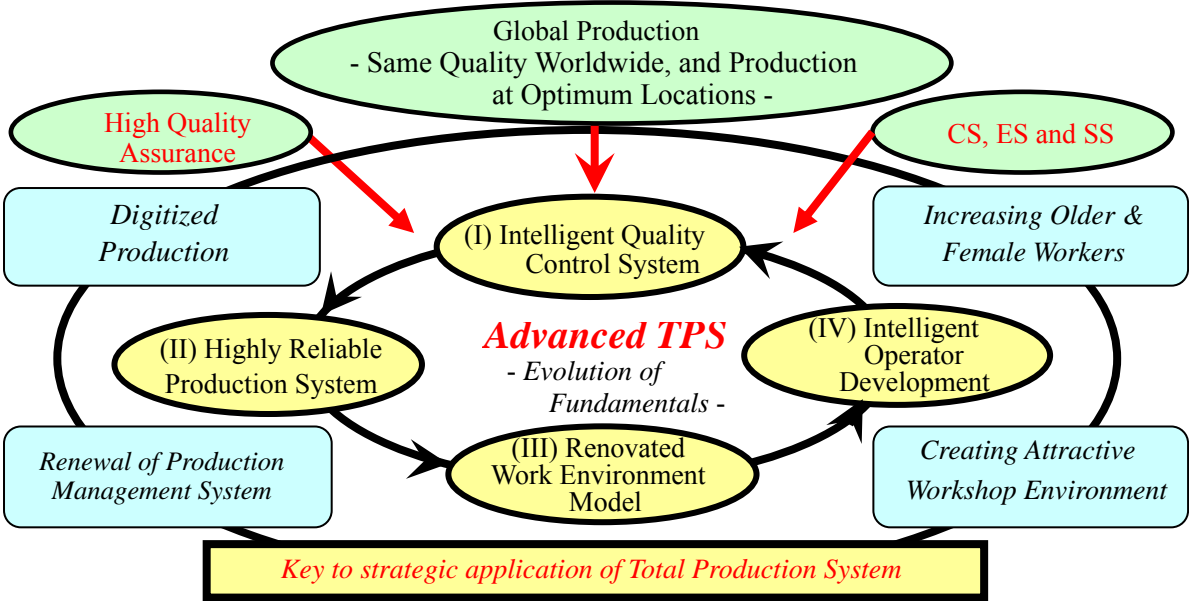


Fig. 4 *Advanced TPS*, A Strategic Development Model of Total Production System

sites and to cultivate intelligent production operators. These measures need to be organically combined and spiraled up in order to make the simultaneous achievement of QCD possible.

One of the technical elements necessary for fulfilling these requirements is the reinforcement of 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, reform is needed for the creation of a next-generation working environment that enhances intelligent productivity. Fourth, intelligent production operators need to be cultivated who are capable of handling the advanced production system and an intelligent production operating system needs to also be established.

In order to offer customers high value-added products and prevail in the “worldwide quality competition”, it is necessary to establish an advanced production system that can intellectualize the production technology and production management system. This will in turn produce high performance and highly functional new products. The author believes that what determines the success of global production strategies is the advancement of technologies and skills that are capable of fully utilizing the above mentioned advanced production system in order to realize reliable manufacturing at the production sites.

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

Global production must be deployed 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 and shortening lead times to reinforce 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, further, production information to organically combine them.

Thus, having recognized the need for a new production system suitable for global production, the author has created the New Global Production Model “NGPM” shown in Fig. 5 to realize the strategic deployment of the “Advanced TPS”. The purpose of this model is to eradicate ambiguities at each stage of the production process from production planning and preparation through production itself and process management, and between the processes in order to achieve a highly reliable production system for global production which will improve the reliability of manufacturing through the clarification and complete coordination of these processes.

More specifically, the model is intended to (i) employ numeric simulation (CAE - Computer Aided Engineering) 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)

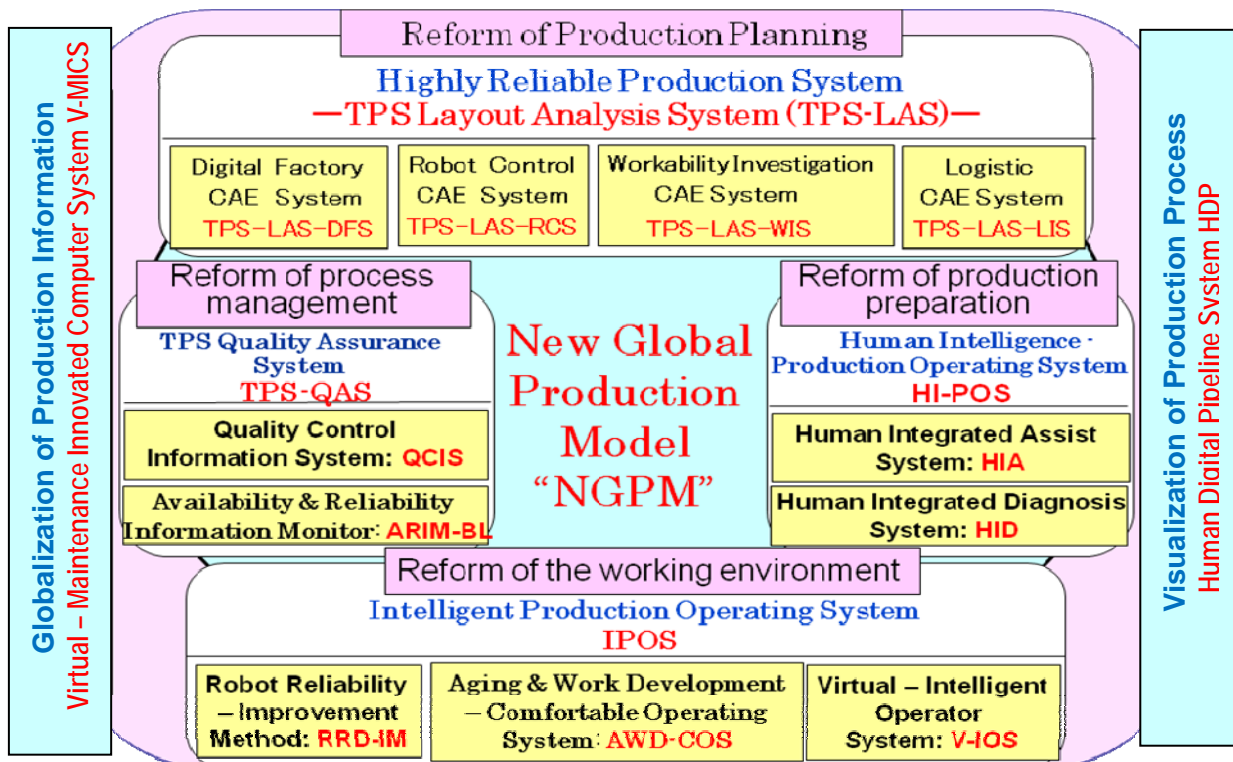


Fig.5 New Global Production Model, NJ-GPM - The Strategic Deployment of Advanced TPS

visualize the above using Information Technology (IT) in order to reform production information systems to create a global network of production sites around the world. The six core technologies that constitute this model and their characteristics are described below.

(1) Reform of production planning: TPS Layout Analysis System (TPS-LAS) is a production optimization system intended to realize 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 [12,15,18]. TPS-LAS is made up of four sub-systems: Digital Factory CAE System (LAS-DFS), Robot Control CAE System (LAS-RCS), Workability Investigation CAE System (LAS-WIS), and Logistic Investigation CAE System (LAS-LIS).

(2) Reform of production preparation: 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, and diagnosis is then carried out to ensure that the right people are assigned to the right jobs [11,12,16,18]. HI-POS is made up of two sub-systems: Human Integrated Assist System (HIA) and Human Intelligence Diagnosis System (HID).

(3) Reform of the working environment: 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 [2, 3,12,17,18]. TPS-IPOS is made up of three sub-systems: Virtual - Intelligent Operator System (V-IOS), Aging & Work Development - Comfortable Operating System (AWD-COS), and Robot Reliability Design - Improvement Method (RRD-IM).

(4) Reform of process management: 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 Cp and Cm [2,3,12,18,19]. TPS-QAS is made up of two sub-systems: Quality Control Information System (QCIS), and Availability & Reliability Information Monitor System (ARIM).

(5) Visualization of production processes: Human Digital Pipeline System (HDP) [18,20] ensures that top priority is given to customers through manufacturing with a high level of quality assurance. This 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 the high-cyclization of business processes within manufacturing.

(6) Globalization of production information: Virtual - Maintenance Innovated Computer System (V-MICS) [2,3,11,12,18,21] is a global network system for the systemization of production management technology necessary to realize a highly reliable production system, which is required to achieve worldwide uniform quality and production at optimal locations.

The created NJ-GPM is fundamental to the strategic deployment 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 author verifies the effectiveness of this research through some examples illustrating the deployment of NJ-GPM.

5. Example Applications

In this section, the author introduces some research examples of 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 Fig. 6 to illustrate a highly reliable production system that has contributed to the reform of production planning [12, 15, 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. On body production lines in particular, where hangers are used to suspend the bodies for each vehicle model, simulations can be used to determine in advance whether there are too many or too few hangers at entrances and exits. Similarly, by predicting downtime when conveyance equipment collisions occur, it is possible to verify in advance whether buffer levels and availability will fall below target levels. Additionally, by determining the optimum number of body hangers and adjusting the main body conveyance routes, these simulations enable reductions in operating efficiency on the lines to be predicted.

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

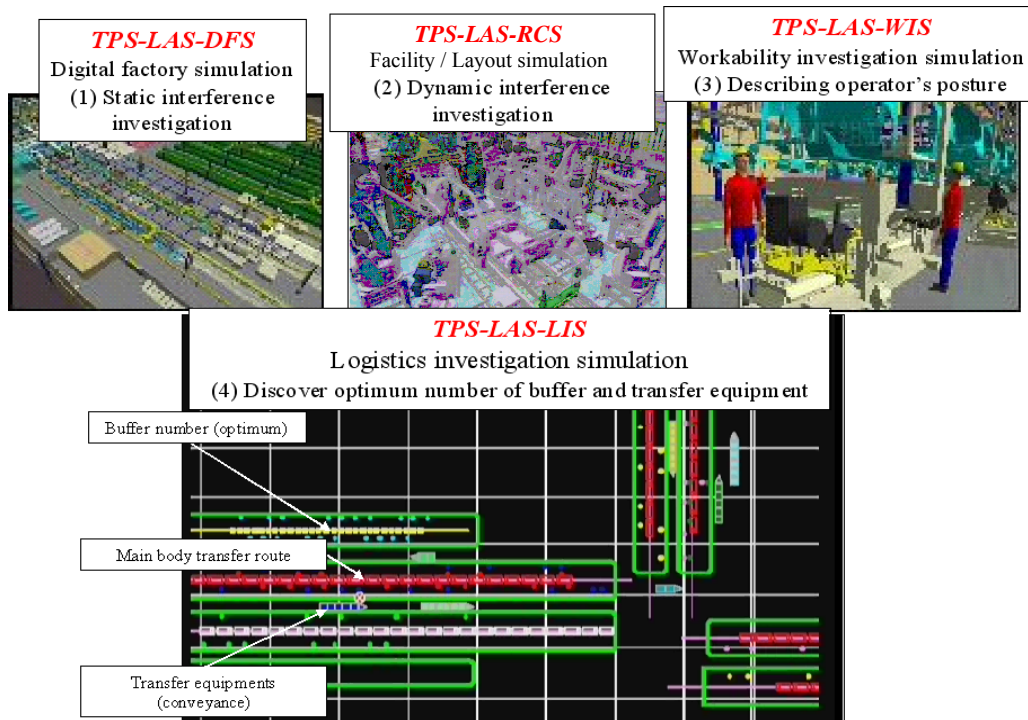


Fig. 6 TPS-LAS, Contribution to the Reform of Production Planning

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 [11,12,16,18]. Fig. 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, (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 (initials of the method's originator and developer, Dr. Jiro Kawakita). 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. Items

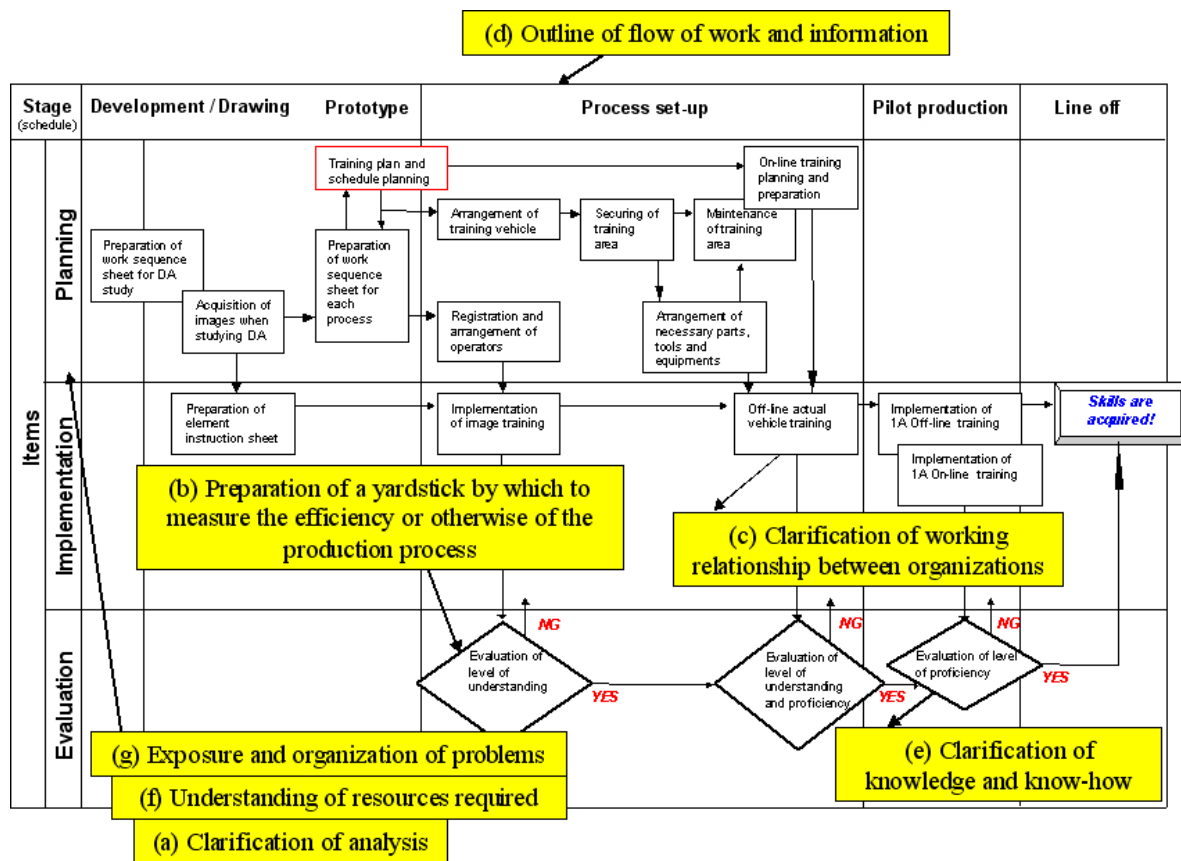


Fig. 7 Total Link System Chart (TLSC) for HI-POS (using both HID and HIA)

taken up (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 (improvements), which is proving to be effective both in Japan and overseas.

5.3 TPS Intelligent Production Operating System (TPS-IPOS)

The authors [2,3,12] are implementing Intelligent Production Operating System (TPS-IPOS) by using three sub-systems. Firstly, 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 Fig. 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

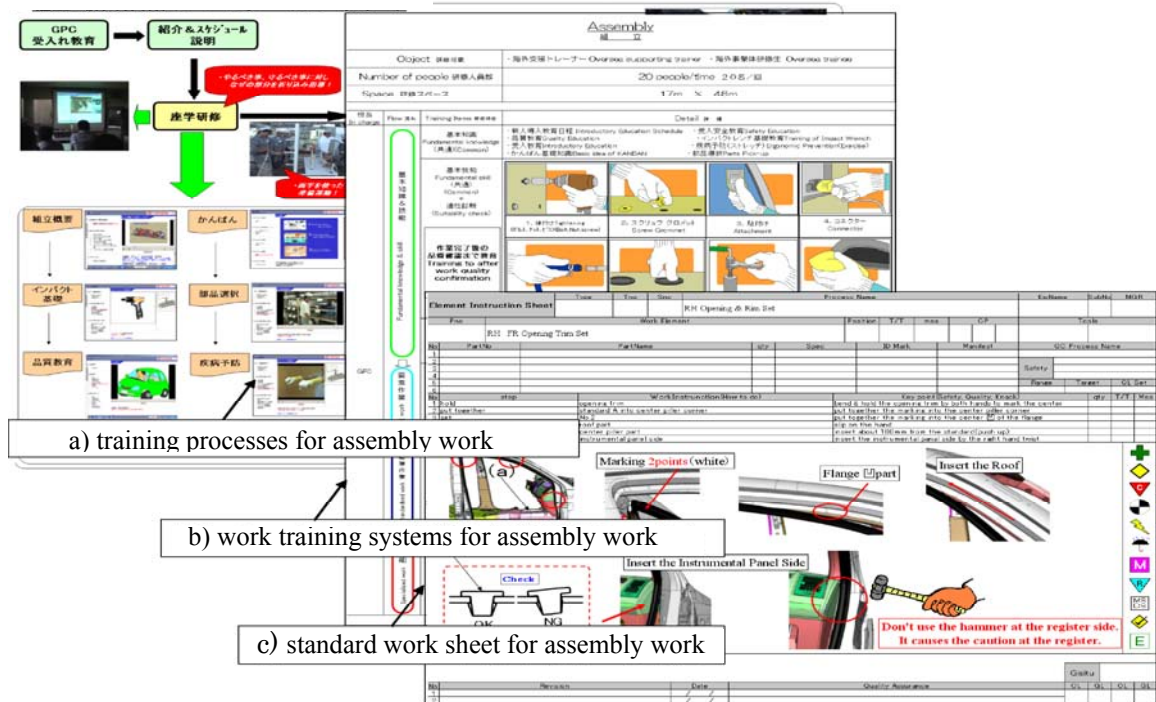


Fig. 8 Virtual - Intelligent Operator System (V-IOS)

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, Aging & Work Development - Comfortable Operating System (AWD-COS) constitutes a fundamental reform of work and labor. Therefore, the authors 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 Fig. 9, as follows; Project I is Arousing motivation in workers, Project II Reviewing working styles to reduce fatigue, Project IV Improving heavy work with

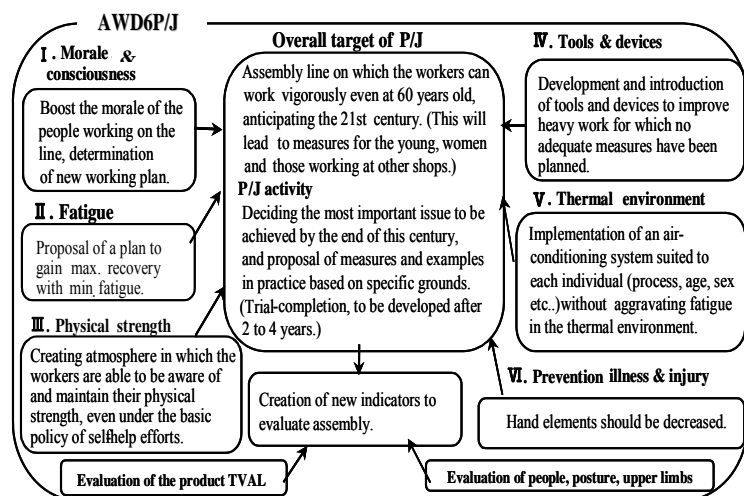


Fig. 9 Aging & Work Development 6 Programs Project

user-friendly tools and equipment, Project V Creating thermal environments suited to the characteristics of assembly work, and Project VI Reinforcing illness and injury prevention.

Thirdly, 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. The body assembly line is a series model with multiple robots positioned as shown in Fig. 10, and so the line's availability is determined by the number of robots introduced. Fig. 11 shows a calculation used to obtain the relation 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.

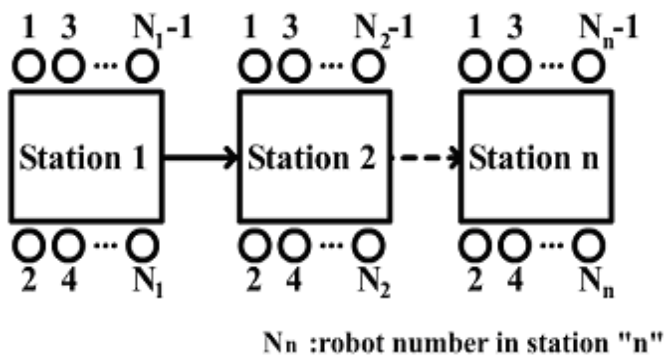


Fig 10 Model showing serial positioning of robots

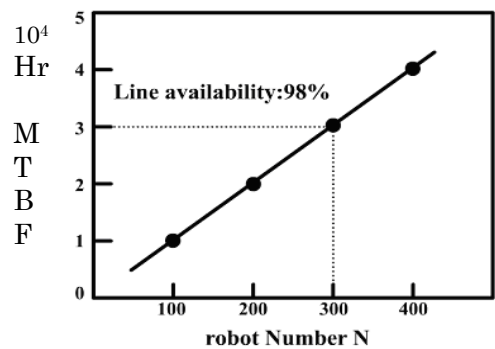


Fig. 11 Relation between the Number of robots and robot MTBF

The use of TPS-IPOS is proving 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 deployment of manufacturing with superior quality and

productivity by integrating two high-precision quality control systems suitable for global production [2,3,12,19]. Firstly, in order to analyze process management status in real time and enable diagnosis of process management abnormalities, Quality Control Information System (QCIS) as shown in Fig. 12, automatically creates control charts using process analysis functions such as 1) scroll function, 2) display of grouped and raw data, 3) innovative factorial analysis by layer, 4) kaizen history database, 5) abnormality diagnosis function, and 6) data links with other application software.

Secondly, 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 Fig. 13. This information is used to carry out Weibull analysis of equipment failures and real time reliability analysis in order to maintain a high level of machine reliability and maintainability, 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.

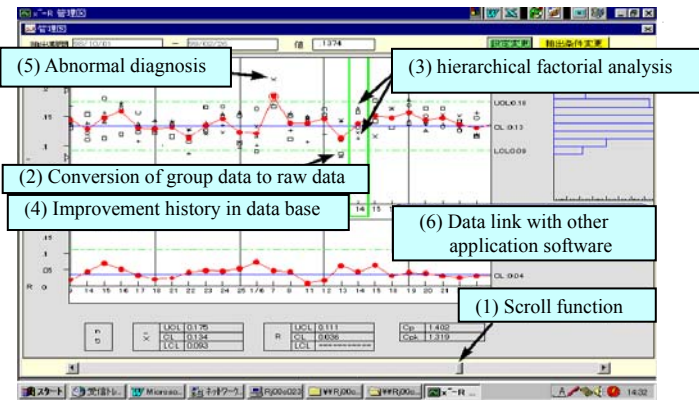


Fig. 12 Outline of Intelligence QCIS

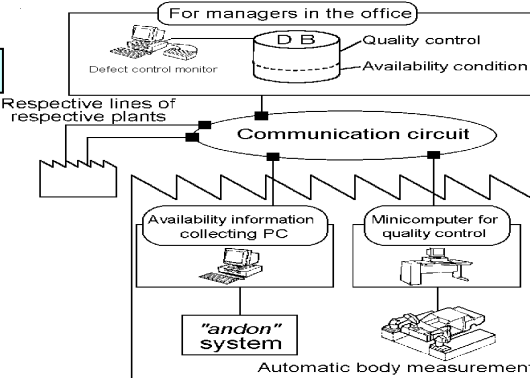


Fig. 13 Outline of Reliable ARIM

5.5 Human Digital Pipeline (HDP)

Human Digital Pipeline (HDP) as shown in Fig. 14 has the following features: (i) HDP creates and supplies in advance “Standard Work Sheets” on which production operators have

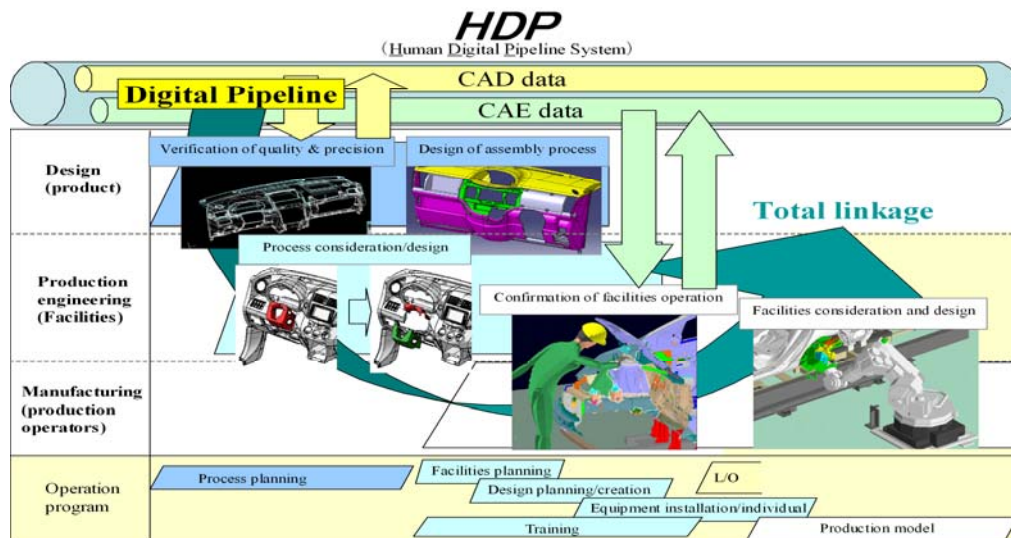


Fig. 14 Outline of Human Digital Pipeline (HDP)

recorded each task in the correct order for jobs such as assembly work, by using design data for new products and facilities prepared from design through to production technology, even if there are no production prototypes [2,3,12,20]. (ii) 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)

Virtual - Maintenance Innovated Computer System (V-MICS) as shown in Fig. 15 takes a server and client system configuration, with a server specially set up for each production site [2,3,11,21]. 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

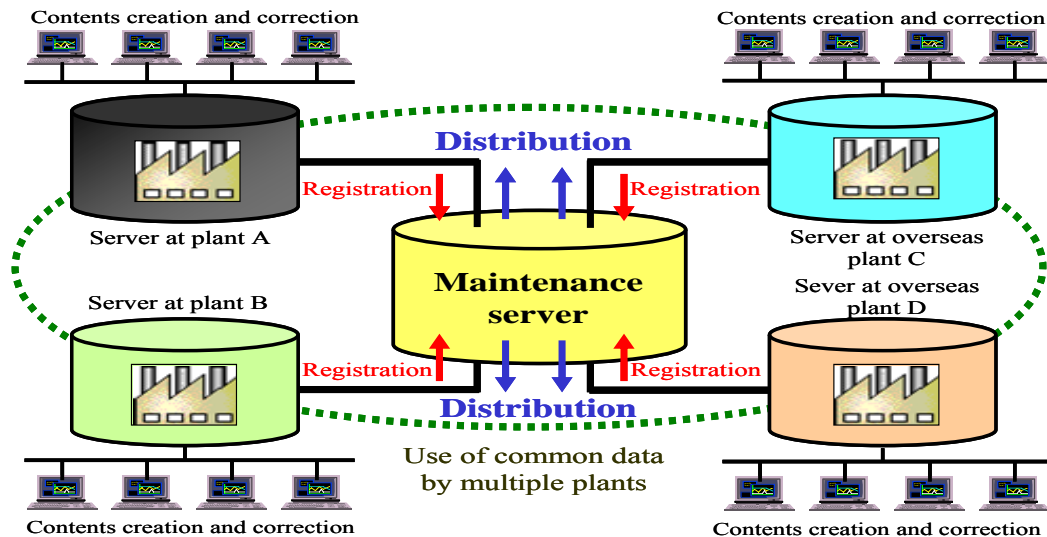


Fig. 15 Outline of Virtual - Maintenance Innovated Computer System (V-MICS)

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 author has created *Advanced TPS* based on the New Manufacturing Theory – Total Production System. The author has also created a “New Global Production Model, NJ-GPM” to enable the strategic deployment of *Advanced TPS*, and its effectiveness has been verified at Toyota.

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