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Strategic HI-POS, Intelligence Production Operating System: - Applying *Advanced TPS* to Toyota's Global Production Strategy -

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Abstract: The authors propose strategic HI-POS as a way of practically achieving intelligent productivity, recognizing the need for the creation of a new, people-centered production system that incorporates rich creativity and the motivation of those involved. Strategic HI-POS is comprised of three core systems that improve the intelligence level of production operators' technology and skills (an intelligent diagnostic method, HID (A), which assists in the discovery of factors inhibiting the attainment of high quality; an integrated assistance system, HIA (B), which links human wisdom to technical evolution and the dissemination of information; and a linkage system, HDP (C), which utilizes a digital pipeline to ensure that intelligent production information is passed throughout a process, from design to manufacturing stages). In addition to this, strategic HI-POS is particularly significant because it offers support for both the next-generation digital engineering systems already proposed by the authors; V-MICS (D), which improves production operators' operational technology abilities in regard to integrated equipment, V-IOS (E), which improves levels of mastered skills and ARIM-BL (F), which progresses the equipment reliability and maintainability by collecting the production line operation information. The authors have applied strategic HI-POS within the cutting-edge corporate environment of Toyota Motor Corporation, and have verified its effectiveness. They are now proposing it as a foundation for Toyota's global production strategy.

Key-Words: strategic HI-POS, Advanced TPS, HID, HIA, HDP, V-MICS, V-IOS, ARIM-BL, Toyota

1 Introduction

In order for Japan's manufacturing industry to realize its goal of customer-first (high quality guaranteed manufacturing leading to success in global production), it is becoming more and more important that consistent levels of quality can be achieved, along with appropriate localization of manufacturing [1].

As can be seen within the automobile industry, overseas production is developing at an extremely high speed, with production being shifted into developed countries such as the USA and Europe, and developing countries within Asia. In response to the increasingly quantitative expansions of overseas plants, simultaneous improvements in productivity and quality assurance are also required, to achieve levels equivalent to those already achieved in Japan.

As high levels of digital engineering-based automation (mechanization involving IT) are increasingly introduced to production lines [2], it is vital that higher levels of ability and precision are realized within production systems to allow these challenges to be met.

The authors believe that production operators are currently required to break away from their conventional attitudes of simple labor operations, and make the shift to a new paradigm of intelligent production operations, which will be more motivational. The authors propose strategic HI-POS (Human Intelligence - Production Operating System), composed of six core systems of HID, HIA, HDP, V-MICS, V-IOS and ARIM-BL, as a way of practically improving intelligent productivity, recognizing the need for the creation of a new, people-centered production system that incorporates rich creativity and the motivation of those involved.

The authors have applied strategic HI-POS within the cutting-edge production environment of Toyota Motor Corporation, and have verified its effectiveness. They are now proposing it as a foundation of Toyota's global production strategy.

2 Strategic Training of Production Operators

The Japanese manufacturing industry is pressing ahead at high speed with moving production bases overseas in order to improve competitiveness. The creation of a production system that can deal with these shifts is an outstanding issue of vital importance. Conventionally, companies have sent experienced, highly skilled trainers from within Japan to these locations and implemented one-to-one skills training of production operators. In this way, since the level to which skills and abilities were passed on to production operators depended on the individual quality of the highly skilled trainer involved, the process was open to confusion when trainers were replaced, since different things would be taught by different people, and as a result, there was a large variation in terms of the skills acquired by production operators. This issue was present not only in overseas plants, but in Japan too.

3 Applying *Advanced TPS* for Global Production Strategy

While manufacturing in workshops is being transformed thanks to digital engineering, the engineering capability in manufacturing workshops often drops, thereby weakening scientific production control for quality incorporation in processes [3]. It is an urgent task to further advance TPS (Toyota Production System) strategically for higher-cycled next-generation production business processes, apart from the conventional experience in success from the viewpoint of global production. The authors, therefore, considered the necessity of including and organically integrating the four elements [4] (production based on information: Information Technology, production based on management: Process Management, production based on technology: Production Technology, and production based on partnership: Human Management) with strategic application of conventional TPS in view of global production, and clarified *Advanced TPS* [5] for the global production strategy as shown in Figure 1 [4].

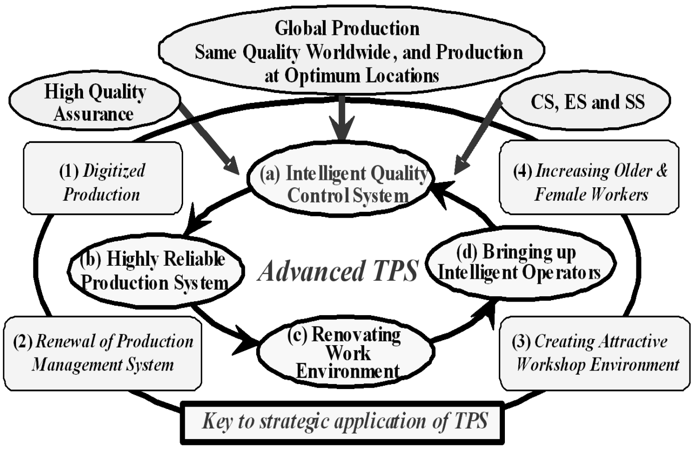

Fig. 1 *Advanced TPS*, global production strategy

The mission of *Advanced TPS* in global deployment is to realize CS (customer satisfaction), ES (employee satisfaction), and SS (social satisfaction) through production that achieves high quality assurance. In implementing *Advanced TPS* for uniform quality worldwide and production at optimal locations (concurrent production), (i) renewal of production management systems appropriate for digitized production and (ii) creating attractive workshop environments tailored to increasing the number of older and female workers are fundamental requirements.

In more definite terms, (a) requires strengthening the process capability maintenance and improvement by establishing an intelligent quality control system. (b) requires the establishment of a high-reliability production system that achieves high quality assurance. (c) involves reformation of the work environment for enhancement of intelligent productivity. (d) requires developing intelligent operators (skill level improvement) and establishing an intelligent production operating system. These factors combined will realize higher-cycled next-generation business processes for early implementation of uniform quality worldwide and production at optimum locations.

4 Proposal of Strategic HI-POS, Intelligent Production Operating System

4.1 Requirements of production operators for intelligent productivity

Production operators are required to be skilled in the operation of integrated equipment utilized in the mass production process, thereby preventing the incidence of breakdowns in individual facilities or overall production systems that result in reduced availability and quality.

In addition to this, due to the fact that in integrated assembly industries such as automobile manufacture there are many areas in which automation cannot provide all the skills required, production operators are also required to have their own specific techniques - knack and key skills (mastered skills), particularly in

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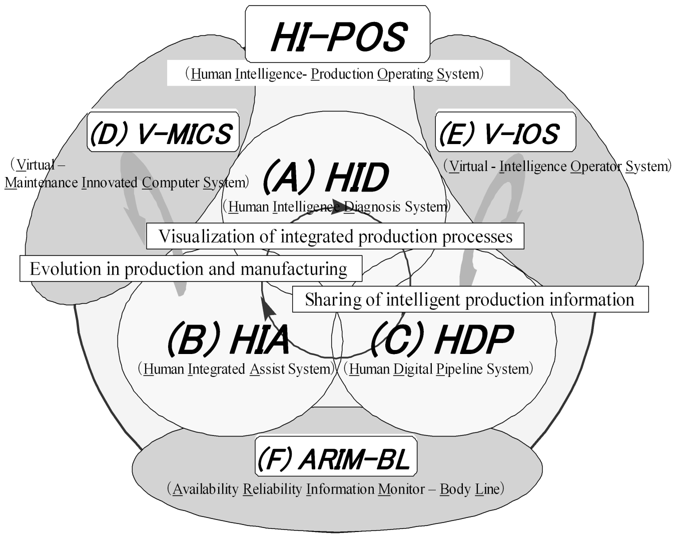

Fig. 2 Strategic HI-POS architecture

the important step of built-in quality. At the same time, manual operation lines, which feature largely in developing countries, and produce smaller quantities, tend to have a wider range of operations than fully automated lines. Workers in these facilities are, therefore, required to have at least the same levels of skills as Japanese workers, if not higher.

4.2 Strategic HI-POS architecture and the six core systems

Based on the viewpoints expressed above, the authors propose that the objective, in other words the improvement of production operators' intelligent productivity, can be achieved through the utilization of the six core systems shown in Figure 2 ((A) HID, (B) HIA, (C) HDP, (D) V-MICS, (E) V-IOS and (F) ARIM-BL), thereby facilitating implementation of a next-generation intelligent production framework. Strategic HI-POS is proposed as this system, with the added benefit of realizing a new, people-centered production system.

The particular features of HID, HIA, HDP, V-MICS, V-IOS and ARIM-BL are outlined below.

4.3 HID: concept and structural elements

Strategic HI-POS, as proposed by the authors, includes a core system that improves the intelligence level of production operators' technology and skills (an intelligent diagnostic method, HID (Human Intelligence Diagnostic System)) (A), which assists in the discovery of factors inhibiting the attainment of high quality and incorporates the following specific features. Firstly, it is important to visualize the availability status of the overall system structure, comprising the equipment, workers, control equipment and computers involved in the integrated equipment line, based on a flow of production-related items and tasks. Secondly, it is important to visualize the production process by converting information relating to control equipment etc. in the integrated production process into production engineering information data [6]. This achieves the clarification of tacit information that to date has existed only as a type of 'black box' in relation to integrated equipment and integrated production processes.

Specifically, HID has been proposed as a system for analyzing problems, proposing countermeasures and making prior evaluations, implementing countermeasures, and making final evaluations of integrated production processes. The system's structural elements are comprised of the seven steps shown in Figure 3 and outlined below.

(1) In the analysis plan proposal, the objectives and policies for analysis are clarified and related persons share relevant information. The following analyses and countermeasures are planned in agreement with related parties.

(2) A fact-finding survey is carried out, based on *genchi-genbutsu* and in line with the objectives and policies for analysis. This survey is divided into the survey and analysis of the overall outline, and a survey and analysis of the details. The former involves gaining an understanding of the outline of the entire process to be analyzed and defining any problem areas. The latter is based on these results and aims to make problem issues still clearer.

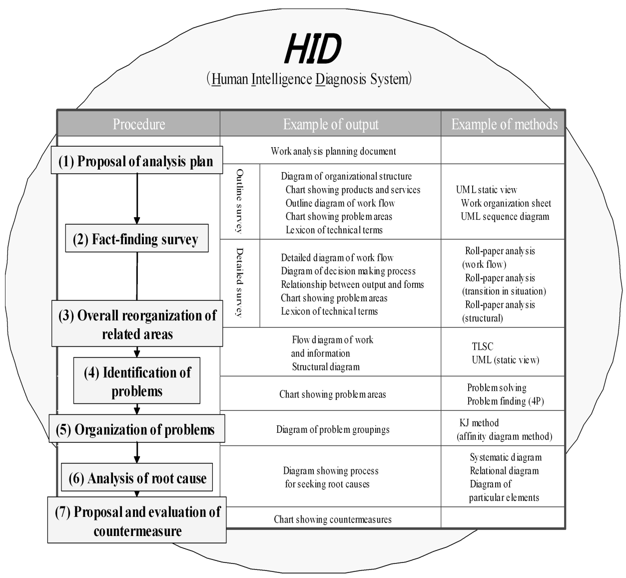

Fig. 3 Concept and structural elements of HID

(3) Overall problem issues are defined in terms of the elements related to both the production process and the production line division (people, production-related items, money, information, time, etc.). The positives and negatives of each of these are analyzed from various perspectives in terms of integrated production processes. Furthermore, the authors have established and are applying a new modeling method, TLSC (Total Link System Chart), which facilitates the consideration of *kaizen* details and methods already implemented.
(4) When tracking down problem areas, TLSC should be utilized, thereby allowing latent problems to also be discovered.
(5) Problem areas should be organized by grouping using the KJ and other methods.
(6) The root causes of problems should be traced using further logical development and appropriate collection and organization of verifying information.
(7) In terms of the proposal and evaluation of countermeasures, the level to which each proposal will implement *kaizen*, as well as the cost of *kaizen*, should be considered.

4.4 HIA: concept and structural elements

The level of performance of production operators should be evaluated using HID, as explained above. In addition to engineering and technical skills, it is important that operators possess a spirit of challenge and creativity, enabling them to realize their own targets, and work with commitment, pride and logic.
For this reason, the authors propose a new core integrated assistance system: HIA (Human Integrated Assist System) (B), which links human wisdom to technical evolution and the dissemination of information to assist in the discovery of factors inhibiting the attainment of high quality. In other words, it supports operators in autonomous *kaizen* activities, enabling them to ask and answer questions for themselves in relation to the work in which they are engaged.
This system comprises the following elements as a means of developing the techniques (knack and key skills) of production operators engaged in standardized tasks, as shown in Figure 4:

(1) Global implementation of same standards,
(2) convenience, and
(3) maintenance/maintainability of intelligent systems.

Implementing this system allows production operators to be autonomous and committed in improving their own mastered skills.

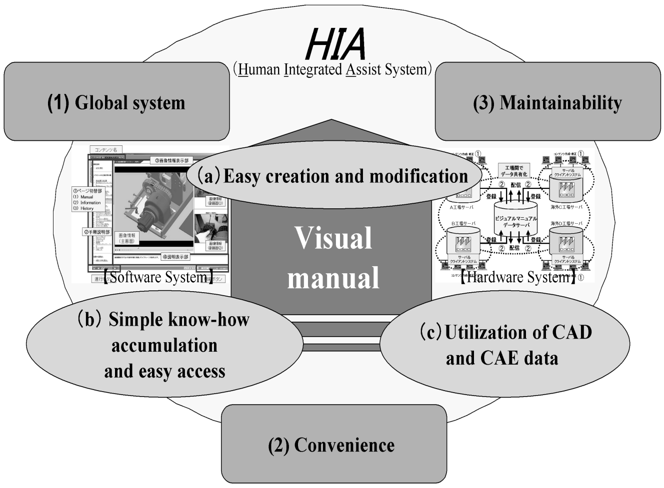

Fig. 4 Concept and structural elements of HIA

4.5 HDP: concept and structural elements

HDP (Human Digital Pipeline System) (C), as proposed by the authors, is a linkage system which utilizes a digital pipeline to ensure that intelligent production information is passed throughout a process, from design to manufacturing stages. It ensures that intelligent production information relating to technical and engineering knowledge in order to facilitate stronger simultaneous startups throughout the world is utilized. HDP facilitates intelligent training, with its increasing requirements for intelligent productivity.
The main structural elements of this system are shown in Figure 5. They include:

(1) the use of design data (even in cases where there is no prototype) relating to a new product, from its design to the production engineering stage, as well as the individual operations used by production

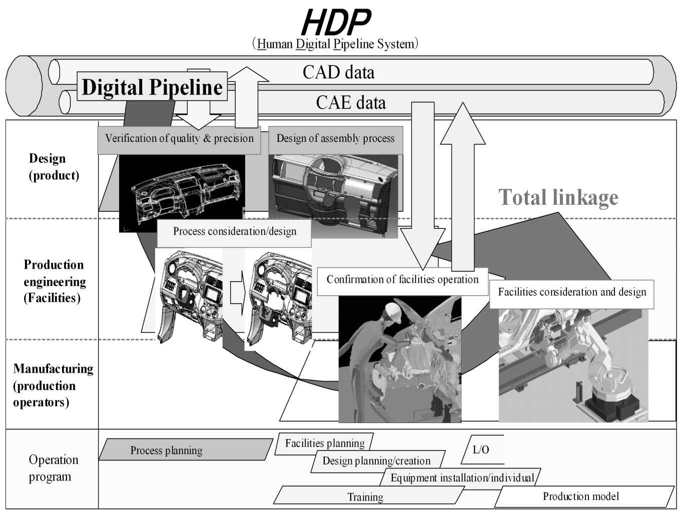

Fig. 5 Structural elements of HDP

operators on the assembly line; all of which are included in a work instruction sheet, which is created in advance.

(2) Facilitating image training in the proscribed order of assembly, even when there is no actual process available to refer to, so that the necessary technical and engineering processes are understood and operators are trained in them from the production engineering process stage.

These elements work to reduce the disparity level between individual production operators, and allow the bottom-up communication of skills to those unfamiliar with them in a short time.

4.6 Intelligent operation support systems: V-MICS, V-IOS and ARIM-BL

The authors have previously proposed V-MICS (Virtual - Maintenance Innovated Computer System) (D) [7]. It acts as a key technology in improving the use of intelligent production techniques in preparation for global production by raising production operators' operational technology abilities in regard to integrated equipment. This system works to make possible support for improvements in production operators' operating skills and techniques. As a result of this, production operators are able to understand the status of their equipment, and establish a system that deals with problems as they occur, resulting in the benefits previously outlined. In addition to this, the introduction of a system incorporating computer graphics and databases into new IT-based operating sheets allows operators throughout the world, who function in different languages, to access a unified understanding of their work. The benefits of this system have already been verified and are now being applied.

The authors have also proposed the intelligence operator educational system V-IOS (Virtual - Intelligence Operator System) (E) [8], which improves the level of mastered skills among production operators. The contribution this system makes to the evolution and dissemination of production operators' mastered skills leads to improved productivity among production operators when setting up a new overseas plant, and the given benefits have already been acknowledged.

In addition, the authors have proposed the availability & reliability information administration system ARIM-BL (Availability Reliability Information Monitor - Body Line) (E) [9]-[10], which defects prevention before occurrence and defects recurrence prevention by quick pursuit of the causes [11]. The equipment reliability and maintainability are improved by collecting the production line operation information through *ANDON* control devices into the defect control monitor for real-time Weibull analysis according to the *Inline-Online SQC* methodology. The results are reflected in prompt improvement of the operating ratio of newly constructed lines.

5 Application of Strategic HI-POS

This section explains the three specific examples of the implementation of core aspects (HID, HIA and HDP) employed in the proposal of strategic HI-POS, and the perceived the effectiveness of this system. In addition to this, the authors have verified application examples of V-MICS [7], V-IOS [8], ARIM-BL [9]-[10] and their effectiveness.

5.1 Implementation and effectiveness of HID

The authors have applied the suggested Human Intelligence Diagnosis System (HID) at Toyota Motor Corporation and implemented 'visualization of advanced production processes' at Toyota's overseas facilities in the production preparation stages [12]. As a result, the authors were able to eliminate what is referred to as 'rework'.

As an example, the operator training processes for the assembly works are shown in Figure 6. The operator training processes are carried out upon model changes to enable production operators to learn how to perform their work accurately in accordance with the operation instruction sheet. In operations such as assembly works in particular, the production operators are expected to complete their work with accuracy within a predetermined time allocation. It is necessary for

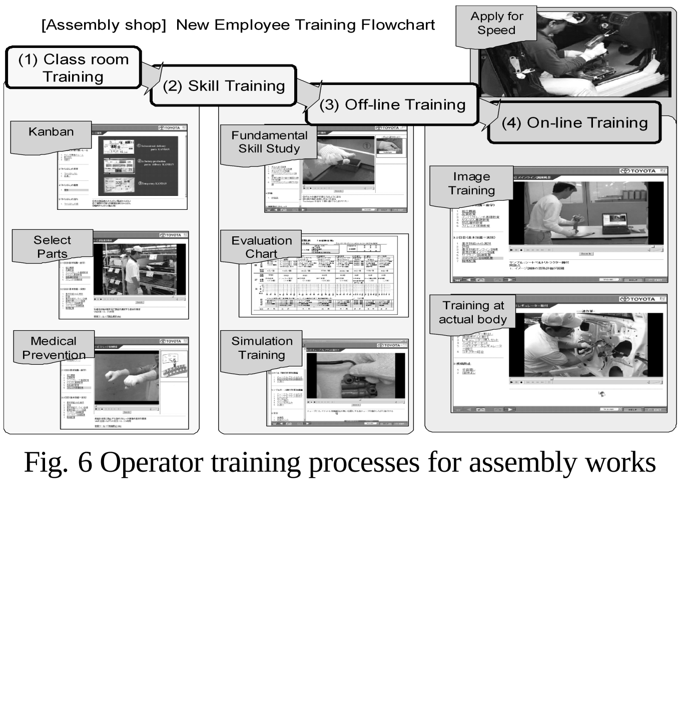

Fig. 6 Operator training processes for assembly works

those operators to reach the target at an early stage before model changeover occurs.

The operator training processes for assembly work provide trainees with (1) class room training, (2) skill training, (3) off-line training, and (4) on-line training in this order.

Once the trainees complete the class room training on quality, safety, etc., they are ready to acquire the skills required for their actual work. Skill training breaks down the fundamental skills into eight categories: (1) Tightening, (2) Screws and grommets, (3) Attaching, (4) Connectors, (5) Hoses, (6) Hole plugs, (7) Flare nuts and (8) Inserting.

The training also identifies techniques (knacks and key points), which are taught in appropriate sequence. The training is repeated until the trainees reach the goals indicated on the evaluation sheet. For off-line training, an actual vehicle will be used and the trainees receive OJT in parts assembly on a stationary vehicle, followed, finally, by the on-line training where they are placed on real assembly lines. The on-line training gives the trainees another OJT opportunity and is conducted at actual line speed.

Figure 7 shows the assembly work training curriculum and traditional and HID training results. The traditional one-to-one method that focused on OJT relying on the individual capabilities of highly-skilled trainers with years of experience in Japan resulted in inconsistency among plants (plants A through D) in terms of training hours required and contents of class room training, skill training, off-line training, and on-line training. Some trainers skipped the off-line training and took the trainees directly to the on-line training stage for exposure to the speed of the actual production line.

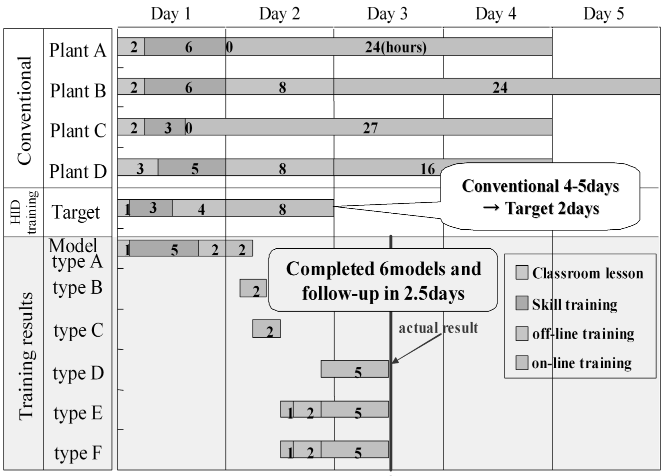

Fig. 7 Training curriculum for assembly works and current status using HID

In contrast, the HID training cut the target completion of the course by more than half, to 2.5 days. It also set the training hours for each segment; class room training: 1 hour; skill training: 3 hours; off-line training: 4 hours; and on-line training: 8 hours. When training was carried out, off-line training took one day and on-line training 1.5 days. The training finished in 2.5 days. The on-line training in this particular case study had to deal with many different model types (model types A to F), which caused some problems. However, it encouraged the authors and led to the conclusion that training could be completed in two days, under normal circumstances.

The trainees traditionally needed four weeks to develop their skills to a level that satisfied the time and accuracy requirements. Under the HID operator training processes, all the trainees were able to acquire the skills in about half that time. An analysis of the result shows the following:

(1) The class room training allowed the trainees to develop more accurate images of their work. The skills training broke down the skills into more detailed elements such as tightening. It clarified the skill level of each individual in specific elements. The training focused on his/her low skill level elements, resulting in quick improvement in the trainee's skills.

(2) The teaching processes and the sequence were clearly identified. It eliminated variation of training by trainers and achieved teaching content and method consistency. Consequently, the training was efficient and resulted in even acquisition of the skills by the trainees.

This case study has proven the effectiveness of the HID operator training processes in faster skills acquisition through breaking down the skills, visualizing the skill level of each individual, focusing on select skills, and repeating training on these specific skills.

A supplementary benefit of these processes was noticed with disabled operators. The operator training for disabled trainees has typically been a special session. The HID operator training processes, however, made it possible to train these operators along with other trainees. It eliminated the need for a special session, contributed to faster skills acquisition, and improved training efficiency. Despite these benefits, the HID operator training processes proved to be slightly less effective than the conventional one-to-one method in some specific work items where operators need to improve their skills to an even higher level. This issue should be studied in the future.

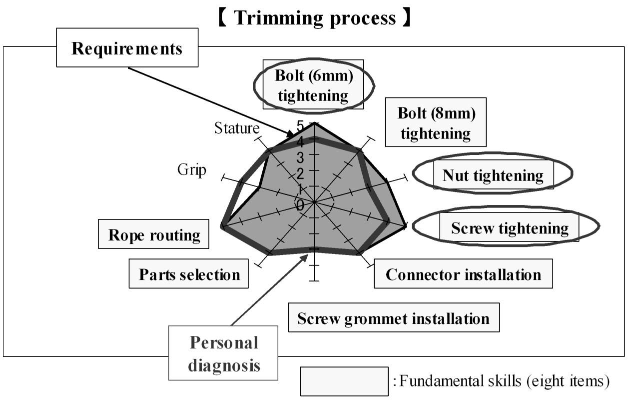

Fig. 8 Example of skill levels between requirements and personal diagnosis

5.2 Implementation and effectiveness of HIA

The skill training for newly employed production operators in Japan and abroad was conducted in the production preparations stage using the proposed HIA system for startup with a stabilized regular production system [13]. Skill training for assembly jobs is explained as an example here. Skill training is conducted for production operators to be able to operate correctly at the time of new plant startup or model change. Especially in the case of assembly jobs, accurate work completion within the specified time is required for target attainment at an early stage before startup or changeover. Since the conventional training used a group of operations for judgment of the training result based on satisfaction of the specified cycle time, it brought about a dispersion in the quality of final products. Before starting skill training, therefore, the functional conditions required for the assigned process are determined individually for preliminary capability diagnosis, to make each trainee aware of his/her weak points and to solve them through training.

To be more precise, an example from the trimming process is shown in Figure 8. Fundamental skills are stratified into eight items: (1) bolt (6 mm) tightening, (2) bolt (8 mm) tightening, (3) nut tightening, (4) screw tightening, (5) connector installation, (6) screw grommet installation, (7) parts selection and (8) rope routing.

The training is conducted with stress placed on bolt (6 mm) tightening and nut/screw tightening, which involves significant differences between requirements and personal diagnosis, making each person aware of, and able to overcome their weak points through training. The training is conducted repeatedly until attainment of the target level by evaluation using the specified evaluation sheet.

While conventional training is aimed at mere satisfaction of the target time specified, the new method uses a visual manual aimed at ensuring each trainee acquires the required skills for specified quality assurance through repeated teaching according to his or her progress for the procedure, broken down into techniques (knack and key points).

Figure 9 shows an example of the visual manual concerning the bolt feeding operation. Accurate motions are visually indicated clearly using still pictures, moving images and animation. The explanatory text under each image describes why the posture is needed, what role it plays in quality assurance or other information from the intelligence operator so as to share the best practices in the world.

Figure 10 shows the learning evaluation conducted for new employees assigned to the trimming process. The learning curve for conventional training consists mainly of OJT using the actual vehicle is compared with the new training using the visual manual. The degrees of learning indicated in time series for the assigned trimming process job according to the individual evaluation sheet (details are omitted) show that it took four weeks until satisfaction of the specified level of accuracy within the specified work time in the case of conventional training, but this was reduced to one half with the new method. The analytical results are as follows:

(1) Training with the visual manual of primarily individual weak points based on personal diagnosis has improved the image of the assigned job, and achieved faster learning compared to the conventional method.

(2) When training with the visual manual is

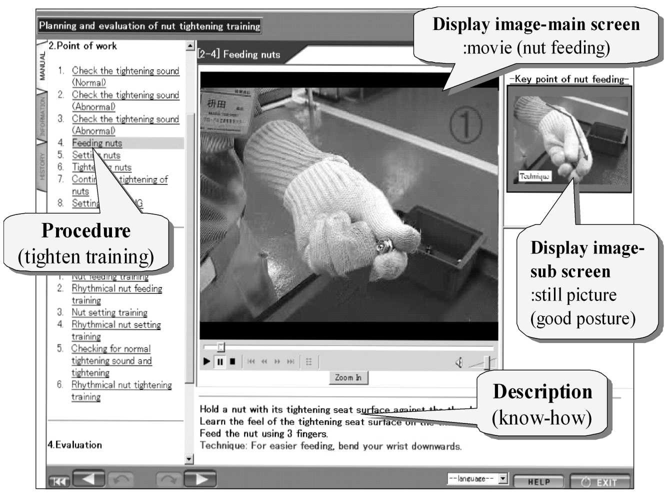

Fig. 9 Example of visual manual concerning bolt feeding operation using HIA

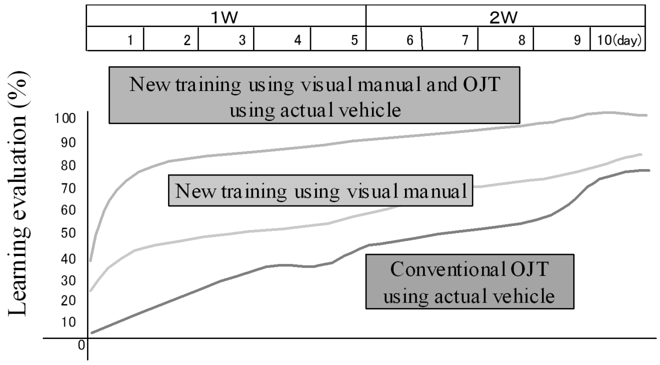

Fig. 10 Learning evaluation for new employees assigned to trimming process

combined with OJT on the actual vehicle, etc., it has been confirmed that the learning speed can be increased through repetition of training that places an emphasis on personal weak points.

(3) Efficient training was attained without dispersion in the degree of learning by teaching the same contents in the same manner according to the clarified teaching process and procedures not dependent on differences between trainers.

5.3 Implementation and effectiveness of HDP

HDP was implemented through the use of component parts design data, which was included in the assembly line work instruction sheet, as shown in Figure 11. Conventionally, production operators underwent training once a new product assembly line was up and running, but in comparison with this, much of the work was able to be done before the startup of the assembly line.

Concretely (a) the design data is utilized in order to make the process more transparent, and to explain the assembly process in a way that is easy to understand. In addition, (b) good and bad examples of areas requiring quality confirmation are displayed using computer graphics.

The system, therefore, contributed significantly to built-in quality and the improvement of availability.

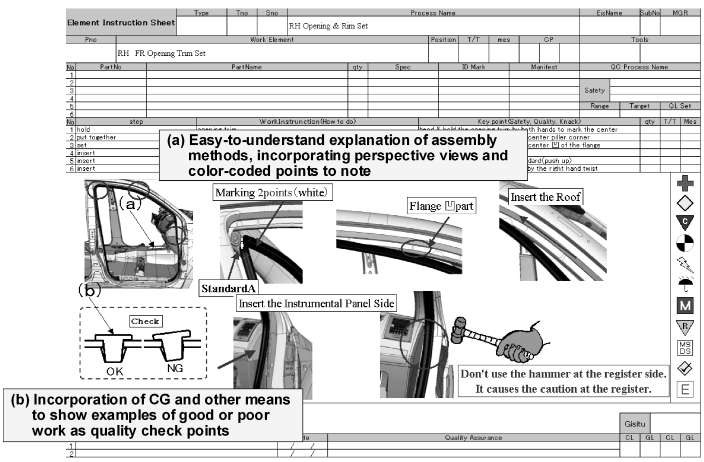

Fig. 11 Example of Work instruction sheet for assembly using HDP

5.4 Effectiveness of strategic HI-POS for global production strategies

The application of the core systems that make up strategic HI-POS gave the following results as anticipated:

(1) Because of an improvement in high-level production equipment and facility operating skills and in facility and equipment reliability, a level of MTBF (Mean Time between Failure) and MTTR (Mean Time to Repair) were achieved in overseas plants equivalent to that of domestic plants, and the target availability ratio in the fourth week after start of production.

(2) According to the correction in the disparity between skills among operators in different countries, the quality disparity was controlled between plants in different countries and achieved a defective production rate equivalent to that of domestic plants.

(3) The bottom-up acquisition of skills by new employees within a short space of time led to the basic knowledge and skills being acquired by new employees in 2.5 days.

As a result of using strategic HI-POS, the target of zero failures was attained at domestic plants two years after the start of the activity in fiscal 2000, thereby establishing a new autonomous production line.

Figure 12 shows that target production quantity (production efficiency) was achieved sixty days, which is 20days move up compared to conventional

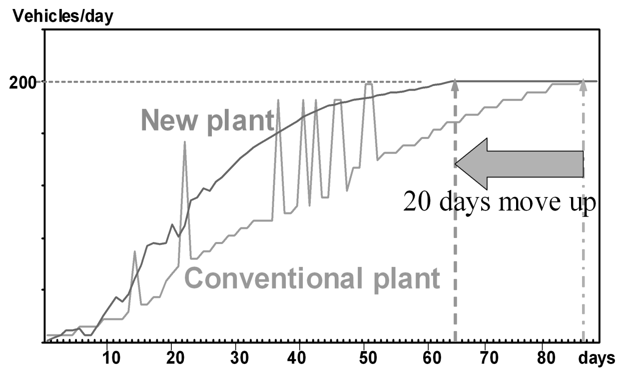

Fig. 12 High production efficiency from the production start-up

plant, from production start-up in a new overseas plant to which the present system was applied. The data therefore indicates that deployment to production lines both in Japan and abroad has been carried out with satisfactory results.

The system has become a cornerstone of Toyota's Global Production Strategy, which requires the same quality of products worldwide, manufactured in the most appropriate location.

6 Conclusion

The authors propose strategic HI-POS as a way forward in the creation of a new, people-centered production system that incorporates rich creativity and the motivation of those involved. Strategic HI-POS offers support for production operators' intelligent production activities through the implementation of V-MICS, which improves production operators' operational technology abilities in regard to high-level equipment, V-IOS, which improves levels of mastered skills and ARIM-BL, which shares intellectual information to maintain or improve the line equipment. In addition to this, strategic HI-POS is comprised of three core systems that improve the intelligence level of production operators' technology and skills (an intelligent diagnostic method, HID, which assists in the discovery of factors inhibiting the attainment of high quality; an integrated assistance system, HIA, which supports technical evolution and the dissemination of information; and HDP, a linkage system which utilizes a digital pipeline to ensure that intelligent production information is passed on throughout a process, from design to manufacturing stages). The authors have applied strategic HI-POS within the cutting-edge production environment of Toyota, and have verified its effectiveness. They are now proposing it as a foundation for Toyota's global production strategy.

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