Strategy for Health and Safety Management at an Automobile Company
—From the Prevention of Low Back Pain to Toyota’s Verification of Assembly Line (TVAL)—

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Abstract: This paper reports on a strategy to improve and renovate assembly lines, including countermeasures to prevent low back pain during the past two decades at Toyota Motor Co. Since 1975, there have been problems with low back pain at Toyota’s vehicle assembly lines. To deal with these low back pain problems, it was necessary to determine their causes and to quantitatively evaluate the burden on workers. For this purpose, functional burden indexes were developed, that is, a posture burden point and a weight burden point were determined to assess the load on the low back, and a low extremity point and a squatting posture point were determined to assess the burden on the leg. The functional burden index, however, could be applied only to specific human functions, not to human functions in general. Since there are about 400 kinds of working patterns in vehicle assembly lines, comprehensive burden index was required to estimate overall burden of such work. Thus, we developed Toyota’s Verification of Assembly Line (TVAL), an index for assessing the physiological stress of an assembly line work, in which an equivalent bicycle ergometer workload is calculated from electromyograms taken of 20 different muscles under actual working conditions. At present, TVAL is used to measure physiological burden of assembly work in order to give priority to improvements, and to objectively demonstrate the effects of such improvements at Toyota.

Key words: Low back pain, Assembly line, Posture burden value, Ergonomics, Stress, Job redesign

Introduction

Herein, we, the staff of the Division of Safety and Health Administration at Toyota, report our strategy for ensuring occupational safety and health at the company, including prevention of low back pain in assembly line workers. We also deal with a further developed concept of Toyota’s verification of assembly line (TVAL), which is aimed at ensuring a healthier and more humane work environment for automobile assembly line workers.

This case report consists of three parts. The first chapter is mainly written by an industrial physician, Tatsuo Iritani.
who provides an overview of Toyota's efforts to deal with occupational health problems including prevention of low back pain. The second chapter is written by Isao Koide who deals with Toyota's methods of evaluating workers' functional capacities to ensure occupational safety and health. Finally, the third chapter is written by Yosinori Sugimoto, who describes a recently developed TVAL (Toyota's Verification of Assembly Line) method aimed at comprehensively preventing occupational injuries, and maintaining and promoting workers' health, as well as improving productivity.

1. Bidecadal Overview of Toyota's Occupational Health Problems Including the Prevention of Low Back Pain

(1) Posture burden index

In the 1970s when a problem of low back pain arose among workers on the final assembly line of automobile production, the Safety and Health Administration staff became concerned about how to decrease the burden on workers by eliminating unnecessary burdens and improving the postures of assembly line workers. This coincided with the company efforts to introduce the concept of product quality control into Toyota's production systems. We therefore attempted to quantitatively evaluate the overburdened postures of workers by doing the following:

a. Using electromyographic (EMG) method, specific worker's postures were classified into 10 grades depending on the muscular burdens expressed as a percent of the maximal voluntary force of contraction.

b. The posture burden of a worker was evaluated by scoring each of the specific postures and the time period of exposure to each specific posture. The posture burden index was expressed by the equation \( \Sigma (\text{posture point} \times \text{exposure time}) \).

c. The acceptability of the posture burden was assessed by the posture burden index. The threshold of the index was 30, based on our experience that the incidence of low back pain is correlated with a posture burden index above 30.

The Safety and Health Administration staff, foremen, forewomen, and production engineers were requested to take an educational training course to learn how to accurately evaluate the posture burden index. This index was also used to improve and renovate various assembly line processes. For example, evaluation of the worker's posture by the posture burden index allowed the staff and engineers to introduce ergonomically designed equipment such as up-down conveyers and tilt hangers into the assembly lines. Consequently, the incidence of low back pain was decreased markedly by this ergonomic improvement of assembly lines.

(2) Low back burden index

The method used to calculate the postural burden index was further developed to permit evaluation of the low back burden. Low back pain is categorized as accidental or non-accidental, according to the official recognition of occupational low back pain in Japan. The former is primarily caused by lifting heavy materials, while the latter is caused by unnatural postures. The Ministry of Labor issued administrative guidelines restricting the lifting heavy materials by harbor workers at port facilities in 1970\(^1\). This restriction, however, was imposed primarily for the purpose of safety management. The risk factors of occupational low back pain include weight, and exposure time, distance, and frequency of heavy material lifting. The low back burden index was calculated in the same way as the posture burden index and a score of 5 was considered an acceptable limit of low back burden index value for the prevention of low back pain. A full explanation of the low back burden index will be given in Section 2-(2).

(3) Comprehensive management of health care including prevention of low back pain

In addition to the above-mentioned ergonomic countermeasures, the following three types of personnel and health care also play an important role in prevention.

Health consultation: Early diagnosis is essential for workers who complain of low back pain. Orthopedists and occupational physicians play an important role in preventing serious low back pain by providing their medical guidance and making recommendations to arrange and replace worker's duties.

Job arrangement: Workers in Japan take two types of health checkup. The aim of the first type is to give new employees appropriate jobs from the viewpoint from their health. The second type involves a medical examination given periodically to ensure the early detection and treatment of work-related diseases. The latter checkup includes the health consultations mentioned above. The physician's advice includes job transfer recommendations for workers who have history of low back pain or those who have high risk of low back pain, judging from their low flexibility of flexion in a standing posture.

Workplace exercise: Conventional exercises are performed to warm up the muscles before starting work. Exercise before
each break is also required to prevent low back pain. This exercise is effective for softening muscles that are used repeatedly during work. Stretching is also obligatory upon completion of work.

At Toyota, the Division of Safety and Health Administration is responsible for workers’ safety and health management. Health management consists of work environment control, work practice management and health care. Because we managed to adequately protect work environment from hazardous chemical and physical agents in the early 1980s, work management was extended to ergonomic improvement of the work conditions and production facilities of each factory. The EMG method was used to evaluate the burden of work postures. Work management has also involved the safety and health problems of older workers, including low back pain. In order to evaluate the time course changes of the various functional capacities of workers as they become older, a concept of functional age with reference to chronological age was introduced in the area of work management. Figure 1 illustrates a concept of functional age which can be evaluated in terms of kinetic, sensory, and mental functions. These three functions can be estimated by physical exercise, physiological, and psychological tests. For example, an evaluation of functional age with an emphasis on the lower extremities and eye sight was used to prevent low back pain and health problems associated with VDT work.

Since we started the comprehensive management of health care in the early 1980s, the number of officially recognized cases of low back pain has decreased markedly, so that there have been only a few cases in the early 1990s. It was through such integrated work management and health care activities that ergonomic countermeasures were found to be effective in preventing occupational injuries including low back pain. Our basic principle of work management is harmonization of work with workers’ functional capacities, as illustrated in Figure 2. Workers’ functional capacities were evaluated by various tests and subject to improvement of the functional capacities and prevention of discomforts. Work demand was subject to task evaluation for ergonomic renovation, leading to workers-friendly production lines and facilities and increased productivity. We have also further developed Toyota’s Verification of Assembly Line (TVAL), a concept of which will be described in detail in Section 3.

### 2. Toyota’s Method to Evaluate Worker’s Functional Capacities

#### (1) Development of the evaluation system

In 1980, we started to seek an appropriate method of evaluating workers’ functional capacities to allow proper job and placement. The method, which was originally based upon “GULHEMP” by L.F. Coile, and completed in 1985. Table 1 illustrates part of this evaluation method with reference to disorders in the lower extremities (L), including

<table>
<thead>
<tr>
<th>Function</th>
<th>Toyota method</th>
<th>Ergonomic evaluation index</th>
<th>Workers capacities evaluation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L₁</td>
<td>Low Back</td>
<td>• Low back Burden Point</td>
<td>&lt;30</td>
<td>standing trunk flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Force [Push/Draw]</td>
<td>&lt;30 kg - f</td>
<td>sit-ups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Weight</td>
<td>&lt;20 kg</td>
<td></td>
</tr>
<tr>
<td>L₂</td>
<td>Leg</td>
<td>• Squatting posture</td>
<td>&lt;30%/takt</td>
<td>side steps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lower Limbs Extremities Burden Point</td>
<td>&lt;30%</td>
<td></td>
</tr>
</tbody>
</table>
low back pain. For instance, the jobs with a risk of low back (L1) can be evaluated by three factors: the low back burden index, the push and pull forces applied to lift and move heavy materials and the weight of materials. The values of these three factors should be set below 30, 30 kgf, and 20 kg at the workplace to prevent low back pain. We can make use of the specific indexes of “ergonomic evaluation” to install production facilities with less burden on workers, leading to improved productivity and lower risk of low back pain. Worker’s functional capacities necessary for the job (L1) can also be evaluated using the results of workers’ physical capacity determined by an aptitude test involving standing trunk flexion and sit-ups. We can make use of these indexes and the aptitude test scores to ensure proper job placement for older workers and inexperienced workers, in order to prevent low back pain among such workers.

(2) Ergonomic job evaluation
Since 1975, the work environment characterized by worker’s assumption of unnatural postures and the lifting of heavy materials in assembly lines has been greatly improved with the implementation of the posture burden index standards and the weight restrictions. Low back pain, however, continued to afflict workers frequently lifting materials weighing 5 kg. In order to cope with such a situation, we developed the concept of the low back burden index in early 1980. This index can be expressed in terms of the posture burden index and weight burden index:

$$\text{Low back burden index} = (\text{posture burden index}) + 2 \times (\text{weight burden index})$$
$$= \sum (\text{posture point} \times \text{exposure time})$$
$$+ 2 \sum (\text{weight} \times \text{holding time} \times \text{distance} \times \text{frequency})$$

(1)

Posture burden index: The postural burden index was calculated by the summation of posture points as the muscular burden of a worker’s specific posture multiplied by the time period a worker spent in that posture. As shown in Table 2, each posture point was scored by referring to the EMG activity expressed as a percent of the maximal voluntary contraction force of the representative muscles. The most severe posture was given the highest score of 10. One point was added, if a twisting motion is involved.

Table 2 shows a chart for calculating the posture burden index for each task. Overload caused by unnatural postures of workers was improved by using the posture burden index given on the chart. For example, ergonomic countermeasures such as adjustment of the height and depth of equipment, reduction of holding time through the improvement of tools and processes, and the creation of a balanced burden by changing the procedures were undertaken to improve the work environment.

Table 2. Low back burden index

<table>
<thead>
<tr>
<th>Operation</th>
<th>Posture element point</th>
<th>Times / Takt (sec)</th>
<th>Times / Shift (hour)</th>
<th>Posture burden index (α)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Element point</td>
<td>10 9 8 7 6 5 4 3 2 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total posture burden index
$$\sum \alpha = \text{Points}$$

(Notes: Add 1 point for twisting back)
Takt was defined as working hours / number of vehicles produced.

Fig. 3. An example of posture improvement in door regulator assembly work

An example is given in Figure 3. When a worker assumed a bending posture in assembling a door regulator at the same floor height as shown in Figure 3, the elemental posture
Table 3. Weight burden index

<table>
<thead>
<tr>
<th>Weight burden index: ( \beta )</th>
<th>Weight burden index: ( \beta = \Sigma ) (W ( \cdot ) N ( \cdot ) L) ( \cdot ) T ( / ) 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \beta = 3 ) (W ( \cdot ) N ( \cdot ) L) ( \cdot ) T ( / ) 1000</td>
<td>( \Sigma (\alpha + 2 \beta) = ) Points</td>
</tr>
</tbody>
</table>

Weight burden index: The low back burden can also be expressed as a function of material weight, handling frequency and distance, and time period. Guidelines for prevention of low back pain issued by the Labor Ministry of Japan in 1970[^1], recommended a weight below 15 tons or 30 \( \times \) 500 kg/day, a frequency of less than 500 times, a holding period of shorter than 2.5 hr, the distance of under 2 km. In addition to the parameters cited in the guidelines, we added a new parameter, height, to evaluate the burden imposed by lifting material from the floor to a certain height, including the shoulder. A weight burden index chart is presented in Table 3. A critical weight burden index above which job and/or facility improvements should be implemented was set at points 15. Referring to the weight burden index chart, ergonomic countermeasures to reduce weight, handling frequency, holding period, distance, and lifting height were provided for job in which the weight burden index exceeded 15. A sample application of the weight burden index is given in Figure 4. Before a synchronized lifter was installed, the weight burden index totaled 10.8 for worker assembling tires weighing 15 kg. The burden index was reduced to zero, because the manual lifting of the tires was replaced by automatic lifting with a lifter.

Low back burden index: It has been recognized in actual workplaces that workers' postures are altered by the weight of materials handled. We developed a concept to permit a more comprehensive evaluation of low back burden by using

[^1]: SHISEIJURYO TEN

Fig. 4. An example of weight burden reduction in tire assembly work
a linear equation that combined posture and weight burden indexes. Figure 5 shows the relation between the two indexes. When the low back burden index exceeded 30, the jobs and production facilities were considered a target of improvement to decrease the low back burden.

Other indexes: Other standards aiming at preventing low back pain were set up for jobs on a conveyor assembly line. These standards recommended a weight under 20 kg, and push and pull forces below 20 kg x f on the basis of the muscle burden when lifting 20 kg weights, and prohibited work forcing very unnatural postures with corresponding element points of 9 and 10.

3. Development of Toyota's Verification of Assembly Line (TVAL)

Four principles were established for the construction of a new vehicle assembly line at Toyota. These were an increase in workers' motivation, the design of a production process that every worker could perform, the installation of worker-friendly automated equipment, and the promotion of a comfortable work environment. To construct an assembly process that satisfy the four principles, effective ergonomic improvements were required. We needed to quantitatively evaluate the burden on assembly line workers, and identified two important points. One was the need to set up priorities for various actions we had to take. Another was the need to predict the possible effects. Therefore, we developed a comprehensive evaluation method, which we called TVAL, in order to satisfy these needs.

(1) Classification of various types of work on an assembly line

There are many different tasks on an assembly line, involving different postures, handling weights, directions of forces, and assembling tools. Assembly line involves approximately 400 different tasks. Therefore, we classified assembly work on the basis of common elements, then evaluated each assembly task to determine the burden on workers by the TVAL method. Figure 6 gives some examples of the classification of the various types of assembly line work.

(2) Physiological stress vs duration time

Figure 7 shows the relationship between physiological stress and time of exposure to the stress. The rate of physiological stress (L%) can be expressed as a function of work intensity and time of exposure to the stress, and is given by the following equation:

\[ L = a \log T + b \log S + c \]

where L, S, T and a, b, c represent the rate of physiological stress, work intensity, time period of exposure to the stress, and the various coefficients, respectively. Human perception
of a given constant work load (W) reaches the limit of endurance curve depending on the time of exposure to the stress as shown in Figure 7. The perceived load is defined as the rate of physiological stress (L\%).

(3) Conversion to a bicycle ergometer

Equation (2) was converted into Equation (3) by developing the concept of the rate of physiological stress to TVAL.

\[ L = d_1 \log T + d_2 \log W + d_3 \]

where T and W are time and work load, respectively and d1, d2 and d3 are the coefficients. In order to apply equation (3) to the evaluation of the burden of assembly work, d1, d2 and d3 have to be determined for each of approximately 400 different assembly tasks, each involving different postures, handling weights, assembly tools, etc. Because it is very difficult to directly determine the three coefficients for each of 400 different tasks and because such a determination is not very accurate, the burden of the assembly work is simulated with a general burden evaluation test using a bicycle ergometer. As shown in Figure 8, the load of the bicycle ergometer is represented by the force of pedaling Wb (N), which is determined by changing the resistance of the ergometer wheel. Coefficients d1, d2 and d3 have the following numerical values:

\[ d_1 = 25.5, \quad d_2 = 117.6, \quad d_3 = -162.0. \]

The load of assembly work is determined by a combination of working posture K and working force WA (N). Expressing the load of assembly work as f (K, WA (N)), we obtain equation (4).

\[ f (K, W_A (N)) = W_b = 9.311 t_c^{0.013} M_A^{0.657} \quad (4) \]

tc is the duration of work and MA (%) is the muscular burden measured as EMG activity and expressed as percent of the maximum voluntary contraction (MVC) of the main muscles used in assembly work. The MVC and MA (%) of assembly work at duration tc (sec) can be obtained by EMG measurement of the 20 main muscles shown in Figure 9. Thus the load of the bicycle ergometer (f (K, W_A (N))) can be converted to an assembly work load.
(4) Measurement of \( M_A \) and conversion to \( f(K, W_A) \)

Using the values of typical work forces, the direction of the working force, and the postures shown in Tables 4 and 5, we measured \( M_A \) (%) for approximately 400 tasks at a duration \( t_c = 5 \) (sec) by changing the handling weight and load. The measurements were carried out using five human subjects, two with assembly line work experience and three without. The mean value of EMG activity for each of the 20 main muscles was used to calculate \( M_A \) (%). Table 6 shows some examples of \( M_A \) values which were found to vary depending on the posture, work load level, and direction of force. On the basis of the measurement of MVC at a duration of 5 sec, the load obtained by the bicycle ergometer \( f(K, W_A (\text{N})) \) was converted to an equivalent assembly work load by using equation (4). The results are shown in Table 7. As a result, we can obtain equation (5).

\[
L = 25.5 \log T + 117.6 \log W - 162.0 \quad (5)
\]

Table 6. Results of measurement of \( M_A \) (example)

<table>
<thead>
<tr>
<th>Posture</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Facing upward</td>
<td>13</td>
<td>14</td>
<td>17</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>2 Standing position</td>
<td>11</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>3 Crouching</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>23</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 7. Results of \( f(K, W_A) \) conversion (example)

<table>
<thead>
<tr>
<th>Posture</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Facing upward</td>
<td>31</td>
<td>32</td>
<td>35</td>
<td>39</td>
<td>45</td>
</tr>
<tr>
<td>2 Standing position</td>
<td>28</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>36</td>
</tr>
<tr>
<td>3 Crouching</td>
<td>34</td>
<td>35</td>
<td>36</td>
<td>49</td>
<td>45</td>
</tr>
</tbody>
</table>

(5) Definition of TVAL value and its evaluation of actual work

Consequently, the rate of physiological stress \( L \) (%) is defined as the TVAL, which represents the quantitative value of the work burden given by equation (4). We needed to verify the consistency between the TVAL value and the subjective work load felt by a worker. The methods of verification considered were two: an absolute and a relative method. The absolute method evaluates the load of a specific task based on how workers feel. As a result, the evaluation values tend to fluctuate depending on the experience and habits of each worker. We therefore selected the relative method to verify the consistency between the subjective work load and TVAL values in a series of tasks with varying random loads. As a result, the correlation between the TVAL value and the subjective load by worker’s feeling was found to be consistently high, approximately 0.8.

(6) Example of TVAL

Figure 10 shows some examples of the evaluation of actual assembly line work using the TVAL method. The TVAL values changed from 25 at a standing posture for front-door gromet screw fixing to 42 for deep forward bending for rear combination lamp installation. Figure 11 shows an analytical method for evaluating the work load by the TVAL method. The assembly work was recorded with a video camera and analyzed to determine working load and behavior using a computer-aided TVAL system. The analytical results led to
the introduction of an automatic variable height system for the assembly line that allows workers to do their jobs with natural postures. The automatic variable height system improved the assembly line working posture from a forward bending one to a standing one, leading to a marked reduction of the TVAL value from 55 to 22. This improvement is illustrated in Figure 12.

### Summary of TVAL

1. A method was developed to convert the load of a bicycle ergometer test to an equivalent workload for assembly work as determined by the working posture, working force, and direction of force.
2. When TVAL values were expressed using the relationship between the load and work duration, these values were highly correlated with the subjective loads perceived by workers.
3. Consequently, the TVAL method was found to be effective for quantitatively evaluating the work burden on an automobile assembly line.

TVAL enables us to correctly select work that needs to be improved and to simultaneously propose modifications to vehicle structure, work combination or work content to reduce muscular fatigue. Consequently, we developed TVAL values assuming the relationship between the duration of a fixed load and the MVC doses not vary sharply from one muscle group to another given that the time for each assembly work element is comparatively short. In the future, we will closely examine this assumption, and revise the developed TVAL system.
References