On the Relationship between Productivity
and Labor Cost of Multi-national Workers in
Overseas Construction Projects*

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ABSTRACT

Oil refinery and chemical plants are constructed by multi-national workers in developing countries. Productivity is defined as a function of actual man-hours and standard man-hours required to complete a job. The author will present equations showing the relationship between labor productivity of multi-national workers and labor cost on the construction site by using seven factors, ie, α : Work volume ratio by each nationality, β : average productivity, γ : unit man-hour cost ratio, δ : performance factor of main nationality on the site, ξ : man-hour ratio, π : combined productivity, and λ : labor cost index, such as

$$\begin{aligned}\lambda &= \frac{\gamma + \xi}{\pi \gamma (1 + \xi)} & \text{or} & & \lambda &= \frac{1}{\pi} - \frac{\alpha}{\beta} \left(1 - \frac{1}{\gamma}\right) \\ \pi &= \frac{1 + \xi \beta \delta}{\delta (1 + \xi)} & \text{or} & & \pi &= \frac{1}{\alpha/\beta + (1 - \alpha)\delta} \\ \text{and } \xi &= \frac{\alpha}{\beta (1 - \alpha) \delta} & \text{or} & & \alpha &= \frac{\xi \beta \delta}{1 + \xi \beta \delta}\end{aligned}$$

When improving productivity by training, improvement of combined productivity and cost reduction are computed by these equations.

Key Words: Productivity, Cost, Multi-national Laborers, Overseas, Plant Construction.

1. Introduction

It is very important for engineering and construction firms to find out for a plant construction project the total labor cost which is based on the productivity of each group of multi-national workers involved. This is also very important for man-power planning, determining the camp size and estimating the total construction cost.

By comparing the standard unit rate⁽¹⁾ of man-hours per unit work with the actual unit rate, productivity of manpower in domestic construction can be determined. This is used to compare total labor cost in both standard and actual cases by multiplying the unit rate and the unit man-hour cost⁽²⁾. However, the author has found that no articles about productivity of manpower of multi-nationalities in overseas projects have been written and published.

In this article, the author gives the following definitions

$$\text{Productivity} = \frac{\text{Standard Man-hour}}{\text{Actual Man-hour}} \quad (3), (4)$$

The author divides multi-national workers into 1st national workers (hereafter, referred to as main national workers), 2nd national workers, and n-th national workers. Then the combined productivity (π) is given by the following equations:-

$$\pi = \frac{1}{n \frac{\alpha_i}{\beta_i}} \dots \dots \dots (1)$$

$$\text{or } \pi = \frac{\alpha_1}{\beta_1} \cdot \frac{1}{n \sum_{i=1}^n \xi_i} \dots \dots \dots (2)$$

Labor Cost Index (λ) is given as

$$\lambda = \sum_{i=1}^n \frac{1}{\gamma_i} \cdot \frac{\alpha_i}{\beta_i} \dots \dots \dots (3)$$

$$\text{or } \lambda = \frac{\alpha_1}{\beta_1} \cdot \sum_{i=1}^n \frac{\xi_i}{\gamma_i} \dots \dots \dots (4)$$

Where,

α_i is referred to as Work Volume Ratio

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of i-th national workers.

$$\text{Therefore, } \sum_{i=1}^n \alpha_i = 1 \dots\dots (5)$$

$$\text{or } \xi_i = \frac{\alpha_i}{\beta_i} / \frac{\alpha_1}{\beta_1} \dots\dots (6)$$

where,

β_i : Average productivity of i-th national workers

ξ_i : Man-hour ratio of i-th national worker's and main national worker's man-hour

π : Combined productivity of all national workers involved

γ_i : Labor unit cost ratio of main national worker's and i-th national worker's unit man-hour cost

λ : Labor cost index, ratio of actual cost of all multinational workers and main national worker's total cost without the aid of other national workers.

Main national workers mean workers having the same nationality as main contractor. In section 2, the relationship between these factors for the case of two national workers is discussed.

2. Two National Workers in Overseas Field Construction, ie, Japanese and Locals working together

2.1 Nomenclature and definition

- (1) α : Work Volume Ratio of Local Personnel Work volume is exhibited by the man-hour (hereinafter, referred to as MH) required by Japanese working on a similar job in Japan(5), (whether totally or partially). Therefore, α shows the ratio of work volume by local workers converted to Japanese man-hours against the total work volume.

$\alpha=1$ means that the whole job was done by local people and

$\alpha=0$ means that the whole job was done by Japanese

- (2) β : Local Average Productivity
This is the average productivity of local workers. The Japanese man-hours required in Japan for field construction is considered the standard.
Therefore,

$$\beta = \frac{\text{Standard MH (Japanese)}}{\text{Actual MH (Locals)}} \dots\dots (7)$$

$\beta = 1$ means that local productivity is deemed the same as Japanese one.

Productivity will vary as depending on the trade or position.

However, β means average productivity of all local workers.

- (3) γ : Unit cost Ratio, Japanese vs Locals
The labor cost shall be "All-in Cost"(6) which contains, except overhead,

all necessary costs such as salary, bonus paid in Japan, air fare, surface transportation, overseas allowance, accommodation charge, food and insurance for Japanese, and wages or salary, bonus, commuting cost, legal reserve, sick leave and annual leave allowances for locals

$$\gamma = \frac{\text{Unit cost of Japanese/MH at jobsite}}{\text{Unit cost of Locals/MH at jobsite}} \dots\dots (8)$$

- (4) δ : Performance Factor of Japanese at Jobsite

Performance Factor at jobsite is an inverse of productivity(7).

When Japanese Productivity becomes worse than that in Japan, for instance, 10% more man-hours are required, then $\delta=1.1$ and Productivity is 0.91.

$\delta=1.0$ means Japanese productivity at the jobsite is the same as in Japan.

- (5) ξ : Man-hour Ratio, Locals vs. Japanese

This is the ratio of total man-hours of locals and Japanese at the job-site. It is nearly the same as the ratio of man-power of locals and Japanese.

$\xi=5$ means that one Japanese is working together with 5 locals to do the construction.

- (6) π : Combined Productivity of Locals and Japanese

This is the total productivity of a combination of locals and Japanese at the jobsite.

$$\pi = \frac{\text{Standard Japanese MH in Japan}}{\text{Japanese MH} + \text{Local MH}} \dots\dots (10)$$

This is a new factor introduced by the author.

- (7) λ : Labor Cost Index

This is the ratio of the actual labor cost against the labor cost of the construction done by Japanese only, without the aid of locals.

This is a new factor introduced by the author.

- (8) The productivity stated herein is not value-added productivity(8), (9) but labour productivity.

This is not individual productivity or efficiency which is measured by a stop watch but group productivity which is measured by man-hours spent for construction(10).

Productivity will be judged by an excess or shortage of man-hours compared with standard man-hours required to complete a job.

2.2 Equations of Productivity in Overseas Construction (Part 1)

Man-hours indicated by factors of locals required to execute the α part of

the job: α/β (11)

Man-hours indicated by factors of Japanese required to execute the rest of the job: $(1 - \alpha) \delta$... (12)

Total man-hours of Y, upsilon, indicated by factors,:

$$Y = \alpha/\beta + (1 - \alpha) \delta \text{ (13)}$$

Therefore, the combined productivity (π) will be expressed by the following equation:

$$\pi = \frac{1}{\alpha/\beta + (1 - \alpha) \delta} \text{ (14)}$$

Fig. 1 shows α -Y in eq. (13), where $\delta=1.0$
Fig. 2 shows α - π in eq. (14), where $\delta=1.0$

FIG. 1 $\alpha - Y$ Curve
Where, $\delta=1.0$

FIG. 2 $\alpha - \pi$ Curve
Where, $\delta=1.0$

Man-hour ratio (ξ) is given by the following equation:

$$\xi = \frac{\alpha}{\beta (1 - \alpha) \delta} \text{ (15)}$$

Therefore

$$\alpha = \frac{\xi \beta \delta}{1 + \xi \beta \delta} \text{ (16)}$$

$$\beta = \frac{\alpha}{\xi (1 - \alpha) \delta} \text{ (17)}$$

x and y indicate average labor unit costs of Japanese and locals, respectively, therefore, labor unit cost ratio (γ) is given by the following equation:

$$\gamma = x/y \text{ (18)}$$

Labor cost of local indicated by factors: $y \cdot \alpha/\beta$

Labor cost of Japanese indicated by factors: $x \cdot (1 - \alpha) \delta$

Therefore, Labor cost index (λ) is given by the following equation:

$$\lambda = \frac{y \cdot \alpha/\beta + x \cdot (1 - \alpha) \delta}{x} \text{ (19)}$$

$$= \frac{1}{\gamma} \cdot \frac{\alpha}{\beta} + (1 - \alpha) \delta \text{ (19)}$$

from eq. (14)

$$\lambda = \frac{1}{\pi} - \frac{\alpha}{\beta} (1 - \frac{1}{\gamma}) \text{ (20)}$$

Fig. 3 shows α - λ in eq. (20), where, $\gamma=1.0$ & $\delta=1.0$

FIG. 3 $\alpha - \lambda$ Curve
Where, $\delta=1.0$, $\gamma=1.0$

2.3 Equations of Productivity in Overseas Construction (Part 2)

Using eq. (16) and eliminating α from eq. (14) yields

$$\pi = \frac{1 + \xi \beta \delta}{\delta (1 + \xi)} \text{ (21)}$$

$$\text{or } \frac{\delta}{1 + \xi \beta \delta} = \frac{1}{\pi (1 + \xi)} \text{ (22)}$$

Substitute eq. (16) into eq. (20) and we have

$$\lambda = \frac{1}{\pi} - \frac{\xi \delta}{1 + \xi \beta \delta} (1 - \frac{1}{\gamma}) \text{ ... (23)}$$

Fig. 4 shows π - ξ in eq. (21) where $\delta=1.0$.

Fig. 5 shows π - λ in eq. (23) where $\delta=1.0$ & $\gamma=20$.

FIG. 4 π - ξ Curve
Where, $\delta=1.0$

FIG. 5 π - λ Curve
Where, $\delta=1.0$, $\gamma=20.0$

Substitute eq. (22) into eq. (23) and we have

$$\lambda = \frac{\gamma + \xi}{\pi\gamma(1 + \xi)} \quad (24)$$

$$\text{or } \pi = \frac{\gamma + \xi}{\lambda\gamma(1 + \xi)} \quad (25)$$

Substitute eq. (21) into eq. (23) and we have

$$\begin{aligned} \lambda &= \frac{\delta(1+\xi)}{1 + \xi\beta\delta} - \frac{\xi\delta}{1 + \xi\beta\delta} \left(1 - \frac{1}{\gamma}\right) \\ &= \frac{\delta(\gamma + \xi)}{\gamma(1 + \xi\beta\delta)} \quad (26) \end{aligned}$$

Fig. 6 shows π - λ in eq. (23), where $\beta=0.5$ and $\gamma=20.0$

Fig. 7 shows λ - ξ in eq. (23), where $\delta=1.0$ and $\gamma=20.0$

FIG. 6 π - λ Curve
Where, $\beta=0.5$, $\gamma=20.0$

FIG. 7 λ - ξ Curve
Where, $\delta=1.0$, $\gamma=20.0$

3. Effect of Training of Local Labor and Increment of Supervisory Capability of Japanese on Labor Cost

Refer to Fig. 8, herewith, $\delta=1.0$ and $\gamma=20.0$.

This shows π - λ curve in eq. (23).

Point 1 shows the case of average local productivity (β) as 0.5, and MH ratio (ξ) as 5.0.

When β is raised to 0.67 by training the local labor, point 1 will move to point 2.

Combined productivity (π) of point 1:	0.5833
Labor cost index (λ) of point 1:	0.3571
Combined productivity (π) of point 2:	0.7223
Labor cost index (λ) of point 2:	0.2885

If point 1 is taken as the origin, point 2 implies that the combined productivity (π) will increase 23.8% and labor cost will decrease 19.2%.

One Japanese who has been trained can supervise 10 locals ie, man-hour ratio (ξ) becomes 10. Then, point 1 will move to point 3. Combined productivity (π) of point 3: 0.5455

Labor cost index (λ) of point 3 :0.2500

The combined productivity will decrease 6.48% and labor cost will decrease 30% compared with point 1.

If these two cases happen at the same time, point 1 will move to point 4.

Combined productivity (π) of point 4:0.6970
Labor cost index (λ) of point 4 :0.1956

The combined productivity (π) will increase 19.5% and labor cost will decrease 45.2%, compared with point 1.

When Unit Cost Ratio (γ) is 10, decrement of labor cost will be 22.2%. When γ is 7, λ will decrease 14.7%. When the two cases, β and ξ increasing, are applied simultaneously, λ will decrease 39.1% and 35% compared with point 1.

This implies that the cost of training is a good investment.

Refer to List 1 for the calculated value of π and λ .

FIG. 8 $\pi - \lambda$ Curve
Where, $\delta=1.0, \gamma=20.0$

LIST OF CALCULATION LABOR COST INDEX (λ) AND COMBINED PRODUCTIVITY (π)

(DELTA = 1.000)							
GAMMA = 20							
X 1	BETA	0.4000	0.5000	0.5833	0.6667	0.7500	0.8750
3.00	LAM	0.5227	0.4600	0.4182	0.3833	0.3538	0.3172
	PI	0.5500	0.6259	0.6875	0.7500	0.8125	0.9063
5.00	LAM	0.4167	Pt 0.3571	0.3192	Pt 0.2885	0.2632	0.2326
	PI	0.5000	1 0.5833	0.6528	2 0.7223	0.7917	0.8958
7.00	LAM	0.3553	0.3000	0.2656	0.2382	0.2160	0.1895
	PI	0.4750	0.5625	0.6354	0.7084	0.7813	0.8906
10.00	LAM	0.3000	Pt 0.2500	0.2195	Pt 0.1956	0.1765	0.1538
	PI	0.4545	3 0.5455	0.6212	4 0.6970	0.7727	0.8864
20.00	LAM	0.2222	Pt 0.1818	0.1579	0.1395	0.1250	0.1081
	PI	0.4286	5 0.5238	0.6031	0.6826	0.7619	0.8810
GAMMA = 10							
X 1	BETA	0.4000	0.5000	0.5633	0.6667	0.7500	0.8750
3.00	LAM	0.5909	0.5200	0.4727	0.4333	0.4000	0.3586
	PI	0.5500	0.6250	0.6875	0.7500	0.8125	0.9063
5.00	LAM	0.5000	Pt 0.4286	0.3830	Pt 0.3461	0.3158	0.2791
	PI	0.5000	1 0.5833	0.6528	2 0.7223	0.7917	0.8958
7.00	LAM	0.4474	0.3778	0.3344	0.3000	0.2720	0.2386
	PI	0.4750	0.5625	0.6354	0.7084	0.7813	0.8906
10.00	LAM	0.4000	Pt 0.3333	0.2927	Pt 0.2609	0.2353	0.2051
	PI	0.4545	3 0.5455	0.6212	4 0.6970	0.7727	0.8864
20.00	LAM	0.3333	Pt 0.2727	0.2369	0.2093	0.1875	0.1622
	PI	0.4286	5 0.5238	0.6031	0.6826	0.7619	0.8810
GAMMA = 7							
X 1	BETA	0.4000	0.5000	0.5833	0.6667	0.7500	0.8750
3.00	LAM	0.6494	0.5714	0.5195	0.4762	0.4396	0.3941
	PI	0.5500	0.6250	0.6875	0.7500	0.8125	0.9063
5.00	LAM	0.5714	Pt 0.4898	0.4377	Pt 0.3956	0.3609	0.3189
	PI	0.5000	1 0.5833	0.6528	2 0.7223	0.7917	0.8958
7.00	LAM	0.5263	0.4444	0.3935	0.3529	0.3200	0.2807
	PI	0.4750	0.5625	0.6354	0.7084	0.7813	0.8906
10.00	LAM	0.4857	Pt 0.4048	0.3553	Pt 0.3168	0.2857	0.2491
	PI	0.4545	3 0.5455	0.6212	4 0.6970	0.7727	0.8864
20.00	LAM	0.4286	Pt 0.3506	0.3045	0.2691	0.2411	0.2085
	PI	0.4286	5 0.5238	0.6031	0.6826	0.7619	0.8810

LIST 1 π and λ Calculated Value

It is said that in the case of European and American contractors, one expatriate works with 20 locals at the jobsite. They are working at point 5.

When $\gamma=20$, labor cost will decrease 49% against point 1 and 27% against point 3.

Combined productivity (π) will decrease 10.2% against point 1 and 4% against point 3.

When $\gamma=10$, labor cost will decrease 36% against point 1, and 13% against point 3.

When $\gamma=7$, labor cost will decrease 28% against point 1 and 13% against point 3.

4. How to utilize Combined Productivity (π) and Labor Cost Index (λ)

π - λ Curve is utilized for:

- (1) evaluation of training cost, i.e., combined productivity will rise and labor cost will decrease by training locals and raising local productivity (Increment β)
- (2) evaluation of Japanese training fee, i.e., combined productivity will decrease by improving supervisory capability of Japanese (Increment ξ)
- (3) evaluation of cost required for improvement of camp and food, i.e., improvement of living environment at the jobsite will serve to raise productivity and labor cost will decrease (Decrement δ).
- (4) Improvement of cost estimation method in future i.e., performance factor will correct unit rates estimated before budget establishment (Correction π).
- (5) Forecasting a great decrement of labor cost by applying items (1) and (2) simultaneously (Increment β and ξ simultaneously).

5. Conclusion

When overseas field construction is executed with the cooperation of locals, the variations in average productivity of locals (β), performance factor of Japanese at jobsite (δ), man-hour ratio of locals vs.

Japanese (ξ), and labor unit cost ratio of Japanese vs. locals (γ) are correlated with construction planning and construction cost, and can be reflected in the correction of unit rates and improved estimation of future construction cost without paying any attention to changes in commodity prices or money exchange rate.

By using these factors, evaluation of construction activity and cost of the past, present and future projects can easily be done on a reasonable basis and optimization of construction labor cost will be realized.

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