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Monitoring Productivity with Earned Value Analysis – A New Approach

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Abstract

Labour has an undeniable effect on a construction project and represents a major source of risk for the contractor. Better (or worse) than expected productivity certainly causes a positive (or negative) impact on the global schedule and cost, and thus must be properly monitored and controlled. Measuring the efficiency of direct manpower is a task ordinarily carried out by many contractors, but keeping records of quantities of work performed and the corresponding man hours is not enough. Some questions remain: (i) what is the overall efficiency of the manpower?; (ii) what is its impact on the project as a whole?; (iii) what is the trend of the labour production rates, and how does it affect the originally estimated scenario? In this paper the authors introduce the concept of Labour Cost Performance Index and Labour Schedule Performance Index and present a methodology for measuring and interpreting productivity and forecasting trends by means of Earned Value Analysis.

Keywords
Labour, productivity, cost performance, schedule performance, earned value

1. Productivity performance

Considering that manpower can represent more than half of a construction project total cost, labour has an undeniable effect on the project financial outcome and represents a major source of risk for the contractor. Better (or worse) than expected productivity certainly causes a positive (or negative) impact on the global schedule and cost, and thus must be properly monitored and controlled.

Generally speaking, deviations in the estimated labour cost occur due to variations of productivity (or production rate). There are several reasons for the discrepancy between estimated and actual production rates:

a) Productivities from similar jobs are used, but cannot be achieved in the field;
b) Labour shortage and absenteeism;
c) Availability of skilled labour;
d) Acceleration (directed or constructive);
e) Adverse or severe weather;
f) Interferences;
g) Cumulative impact of multiple changes and rework;
h) Training and motivation; etc.

Measuring the efficiency of direct manpower is a task ordinarily carried out by many contractors, but keeping records of quantities of work performed and the corresponding man hours is not enough. It is important to compare what has been done to what was originally planned and forecast the cumulative productivity at the completion of the job. In other words, the scheduler/planner must be able to assess the performance of the field crews and evaluate the trend in the future.

Some questions remain: (i) what is the overall efficiency of the manpower?; (ii) what is its impact on the project as a whole?; (iii) what is the trend of the labour production rates, and how does it affect the originally estimated scenario?; (iv) what actions must be taken to bring the job to the desired standards?

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In this paper the authors propose a methodology for measuring and interpreting productivity and forecasting future behaviour by means of Earned Value parameters not referred to in terms of dollars, but rather in hours — the concept of Planned Hours, Actual Hours and Earned Hours are the basis of the proposed technique.

2. Control Unit

During the process of construction cost estimating, the work breakdown structure (WBS) of the project is used to detect the services to be estimated. The unit cost of each one of them is calculated by means of a cost spread that depicts the cost categories included in it — labour, material, equipment. Due to the fact that the unit cost spread portrays the production rate of the manpower, it is a very important tool to the planner. It can be stated that productivity is the numerical tie-in of estimating and planning.

The planner/scheduler shall bear in mind that the major responsibility is not only to forecast the production to be performed, but also to establish a practical method for the project control team to monitor actual site production. A recommended practice is defining each activity of the WBS as a control unit. This is pretty much what PDCA circle advocates: (i) the planning team prepares the schedule (plan – P); (ii) the site production team executes the job (do – D); (iii) the project control team checks the job (check – C); (iv) the full team defines future corrective and preventive actions (act – A). Hence, it is fundamental that all team members involved in the job understand the control unit of the scope of work.

3. Planned, Actual and Earned hours

The concept of Planned Hours (PH) derives from Earned Value Analysis (EVA). For a given activity, Planned Hours is the total hours budgeted to be completed during a certain time period. It is the budget assigned hours of work scheduled. In other words, PH equals the assigned quantity to be performed multiplied by the number of man hours required for one unit of the activity (productivity).

For example, if the schedule shows that in Week 1 the estimated quantity of excavation is 100 cy and it takes a labourer 5 hours to dig 1 cy, PH = 5 x 100 = 500 hours. (Although the traditional planned value of EVA is given in dollars [money], PH is always given in *hours* [time]).

Earned Hours (EH) is the estimated hours for completing the work effectively performed in a given time period. EH corresponds to the time initially budgeted for completed work. For example, if during Week 1 the labourer excavated 80 cy, EH = 5 x 80 = 400 hours.

Actual Hours (AH) is the total hours for completing the work in a given time period. AH corresponds to the time actually spent during the time period for completed work. For example, if during Week 1 the labourer spent 420 hours to excavate 80 cy, AH = 420 hours. Please note that AH does not refer to scheduled quantities, but to effective production.

Some numerical relationships can be defined to measure performance of the crews:

a) **Labour cost performance index (LCPI)** is calculated by the formula:

$$LCPI = EH / AH$$

b) **Labour schedule performance index (LSPI)** is calculated by the formula:

$$LSPI = EH / PH$$

LCPI represents how earned hours relate themselves to actual hours. It refers to the efficiency of the crew. Major conclusions are:

- If **LCPI > 1**, it means that the crew has achieved a better than expected performance because each hour effectively worked generated more than one earned hour and thus performance is good — the causes of the improvement must be found and enhanced;
- If **LCPI < 1**, it means that the crew has achieved a worse than expected performance because each hour effectively worked generated less than one earned hour — corrective and preventive measures must be sought for;
- If **LCPI = 1**, it means that the crew is right on target.

Labour schedule performance index (**LSPI**) represents how much earned hours are being added by the actual hours, whereas **LSPI** refers to the physical progress of the project. Major conclusions are:

- If **LSPI > 1**, it means that the crew has completed more than planned and thus performance is good — the causes of the improvement must be found and enhanced;
- If **LSPI < 1**, it means that the crew has completed less than planned and thus performance is bad — corrective and preventive measures must be sought for;
- If **LSPI = 1**, it means that the crew is right on target.

4. Case study

4.1. Planned schedule

Table 1 shows the quantities of a mechanical construction job and the respective estimated productivity.

Activity	Unit	Quantity	Man hours / unit	Total man hours
Assembly of primary cable tray	m	2,000	3.0	6,000
Laying of multicable on cable tray	m	60,000	0.30	18,000
Connection of multicable into junction box	ea	360	0.25	90
Connection of multicable into panel	ea	360	0.25	90
Multicable continuity test	ea	360	0.20	72
Installation of cable tray cover	m	2,000	0.10	200
Total estimated hours				*24,452*

Table 1. Job quantities and planned man hours

In this study, the number of man hours of each activity is the sum of hours of all workers in the crew — for example, if the assembly of 1 ft of tray requires 1 hour of electrician and 2 hours of labourer, the direct manpower is considered to be 3 hours. In other words, performance is measured for the crew, not for each labour trade individually. This gives a better idea of how the team as a whole is proceeding in the job, and helps the foremen in their daily work of controlling the hours spent in each task.

The planned schedule of the job is shown in Table 2. It contains the distribution of man hours per week (PH), which is the period of production control:

			Week									
Actitivity	**Qty**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Assembly of cable tray	m	2.000	286	286	286	286	286	286	286			
	PH	6.000	857	857	857	857	857	857	857			
Laying of multicable on cable tray	m	60.000			10000	10000	10000	10000	10000	10000		
	PH	18.000			3000	3000	3000	3000	3000	3000	0	0
Connection of multicable into junction box	ea	360							180	180		
	PH	90							45	45		
Connection of multicable into panel	ea	360								180	180	
	PH	90								45	45	
Multicable continuity test	ea	360										360
	PH	72										72
Installation of cable tray cover	m	2.000									1000	1000
	PH	200									100	100
Weekly man hours	*PH*	**24.452**	857	857	3857	3857	3857	3857	3902	3090	145	172
Cumulative man hours	*PH*		857	1714	5571	9429	13286	17143	21045	24135	24280	24452
% of total man hours			4%	4%	16%	16%	16%	16%	16%	13%	1%	1%
Cumulative %			4%	7%	23%	39%	54%	70%	86%	99%	99%	100%

Table 2. Planned schedule (with quantities and man hours)

The S-curve obtained from the planned schedule is the cumulative Planned Hours (PH) curve (Fig. 1), which is the baseline for labour performance monitoring.

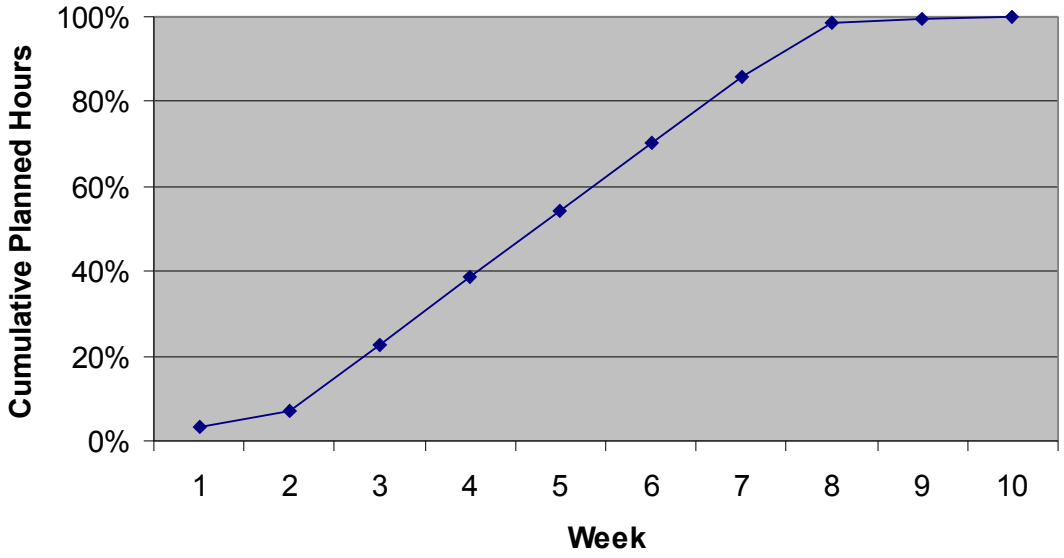

Fig. 1. Cumulative Planned Hours (PH) per week

4.2. Actual progress

During 3 weeks, actually performed quantities and man hours were recorded (Table 3). These are Actual Hours (EH). Percentages are based on the total man hours previously estimated (24,452 hr).

Actitivity		Qty	Week 1	2	3	4	5	6
Assembly of cable tray	m	1.020	300	400	320			
	AH	2.580	860	860	860			
Laying of multicable on cable tray	m	3.000			3000			
	AH	1.000			1000			
Weekly man hours	*AH*	**3.580**	860	860	1860			
Cumulative man hours	*AH*		860	1720	3580			
% of total man hours			4%	4%	8%			
Cumulative %			4%	7%	15%			

Table 3. Job progress (actual quantities and man hours)

4.3. Earned hours

Earned Hours (EH) are calculated by multiplying the actual quantities by the estimated number of hours per unit. So, for the assembly of cable tray, EH in the 1st week equals 300 m x 3.0 hr/m = 900 hr (Table 4).

Actitivity	Rate (hr/un)	Qty		Week 1	2	3	4	5	6
Assembly of cable tray	3,00	m	2.000	300	400	320			
		EH	3.060	900	1200	960			
		LCPI		1,05	1,40	1,12			
		LSPI		1,05	1,40	1,12			
Laying of multicable on cable tray	0,30	m	60.000			3000			
		EH	900			900			
		LCPI				0,90			
		LSPI				0,30			
Weekly man hours		*EH*	**3.960**	900	1200	1860			
Cumulative man hours		*EH*		900	2100	3960			
% of total man hours				4%	5%	8%			
Cumulative %				4%	9%	16%			
		Overall LCPI		1,05	1,40	1,00			
		Overall LSPI		1,05	1,40	0,48			

Table 4. Earned hours

The conclusions to which the project controls engineer come are:

- 1st week – planned hours (857 hr) are very close to actual hours (860) and earned hours (900), what means that the project is slightly ahead of schedule. These result are numerically shown as LCPI = 1.05 (good performance in productivity) and LSPI = 1.05 (ahead of schedule);
- 2nd week – EH is much higher than PH and AH, what means that the team was very efficient. The reason is that the assembly team achieved very high productivity. LCPI = 1.40 (good performance in productivity) and LSPI = 1.40 (ahead of schedule);
- 3rd week – EH equals AH, but is much lower than PH, what indicates that in the period the team achieved the desired productivity, but delivered much less product than expected. LCPI = 1.00 (on target) and LSPI = 0.48 (behind schedule).

4.4. Labour performance

To date, i.e., cumulatively, the general labour performance is in Table 5.

	Week 1	2	3
PH	857	1714	5571
cumul.	4%	7%	23%
AH	860	1720	3580
cumul.	4%	7%	15%
EH	900	2100	3960
cumul.	4%	9%	16%
LCPI	1,05	1,22	1,11
LSPI	1,05	1,23	0,71

Table 5. Cumulative Planned, Actual and Earned hours

A brief analysis of LCPI behaviour reveals that productivity factor has always been higher than 1, but with a steep decline in week 3 (Fig. 2) due to the low productivity of the laying of multicables. The team must be aware that this activity plays a key role in maintaining the good performance of the first weeks.

At the end of the 3rd week, LSPI = 0.71. This is the difference between planned progress (23%) and the real progress (16%). The conclusion is that the project is late by (1 – 0.71) x 21 days (elapsed time) = 6 days (Fig. 2).

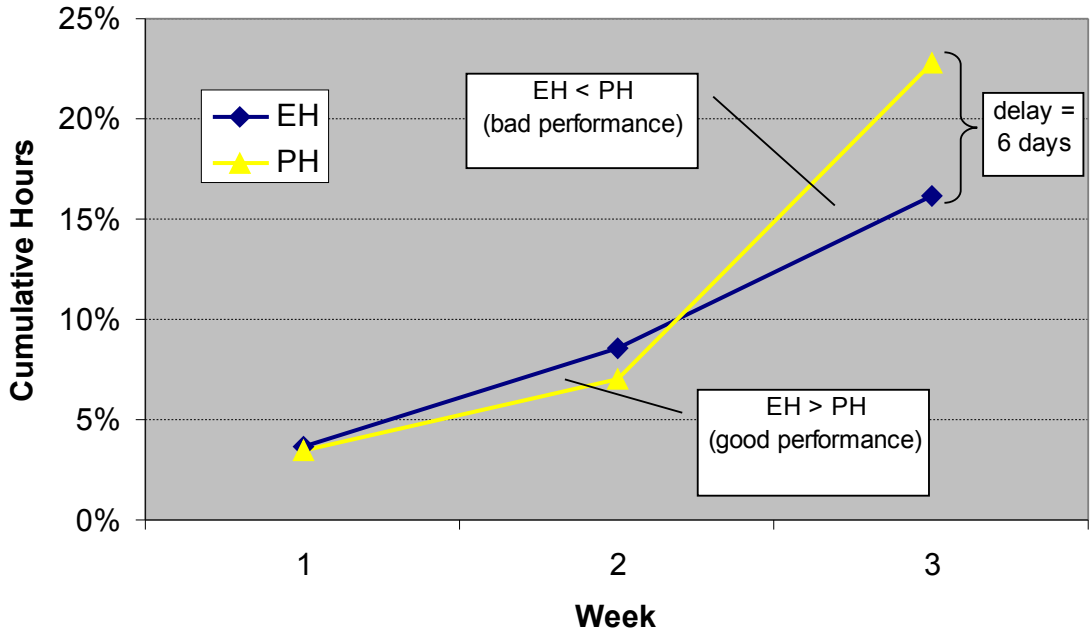

Fig. 2. Comparison of Earned and Planned hours

4.5. Estimate at completion (trend)

Defining trend means forecasting the final outcome of an activity and, by extension, of the project. For a given activity in progress, its estimate to completion takes into account the current status and a projection based on its actual labour performance. For activities still to start, planned productivity is assumed to be true.

In our case, for assembly of cable trays, the actual work performance is given by 2,580 hr divided 1,020 meters = 2.53 hr/m, lower than planned (3.0 h/m). Since the remaining quantity to perform is 980 m, it shall still take to 2.53 x 980 = 2,479 hr to finish the job and thus a total of 5,059 hr, 941 hr lower than the 6,000 planned hours (Table 6).

Actitivity		Quantity	Planned Rate (hr/un)	Status Week 3						
				Actual Hours (hr)	Performed Quantity	Actual Rate (hr/un)	Remaining Quantity	Remaining Duration (hr)	Total Duration (hr)	Planned minus Forecast (hr)
Assembly of cable tray	m	2.000	3,00	2.580	1.020	2,53	980	2.479	5.059	941
Laying of multicable on cable tray	m	60.000	0,30	1.000	3.000	0,33	57.000	19.000	20.000	-2.000

Table 6. Projection (trend)

For the first activity, the savings of 941 hr corresponds to 941/857 = 1.1 week (= 8 days); for the second activity, the delay represents 2,000/3,000 = 0.66 week (= 5 days). An outstanding conclusion is that the job needs to take a corrective action to minimize the delay in laying cables — a solution would be to increase the crew size by 1/0.66 = **50%**.

4.6. Conclusion

The concepts of labour cost and labour schedule indices are an important control tool. By gathering field actual quantity performed and the corresponding man hours, actual productivity can be obtained and used as a forecasting parameter to the estimate at completion. Without entering in usually hard to implement full cost analysis required by EVA, the labour performance indices provide the project control team with a real insight of the job progress and its trend. The methodology is relatively easy to apply in real construction projects and the results are invaluable to the team members.