American Journal of Engineering and Technology Management
2022; 7(1): 1-7
http://www.sciencepublishinggroup.com/j/ajetm
doi: 10.11648/j.ajetm.20220701.11
ISSN: 2575-1948 (Print); ISSN: 2575-1441 (Online)

Science PG
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Valuation: A New Approach to Measure the Performance of Last Planner System

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To cite this article:
Osama Abusalem. Valuation: A New Approach to Measure the Performance of Last Planner System. *American Journal of Engineering and Technology Management.* Vol. 7, No. 1, 2022, pp. 1-7. doi: 10.11648/j.ajetm.20220701.11

Received: December 6, 2021; **Accepted**: December 23, 2021; **Published**: January 12, 2022

Abstract: The Last Planner System (LPS) is a production planning and control system that utilizes the lean construction philosophy to improve workflow reliability. Although there are several metrics developed to measure the performance of LPS, the current metrics fail to genuinely reflect the actual performance of LPS. The literature review shows no evidence of existing researches that provide a holistic approach to measure the performance of LPS. Consequently, this research aims to propose a new holistic approach to measure the performance of LPS called valuation. The objectives of this research are: (1) to provide an overview of the current metrics used to measure the performance of LPS, (2) to propose 10 steps to measure the performance of LPS based on the valuation approach, (3) to utilize the valuation approach to derive numerous metrics based on all possible relationships between the main and sub (i.e., activity and constraint) categories of LPS that currently available or may emerge in the future. This research contributes to the body of knowledge by deriving metrics based on the valuation approach that are significantly more comprehensive and mathematically more robust since they integrate several criteria and rely on the value rather than the number or amount of activities or constraints. Hence, the valuation approach generates more accurate results. Moreover, the valuation approach can help the construction professionals to track the performance of LPS across phases or even projects by accumulating the data and measuring the proposed metrics.

Keywords: Lean Construction, Last Planner System, Approach, Valuation, Metrics

1. Introduction

The benefits, challenges, variation causes and critical success factors associated with Last Planner System (LPS) implementation is well-documented in diverse environments around the world [1]. Moreover, there are several metrics developed to measure the performance of LPS [2]. Unfortunately, however, the current metrics neglect not only the value of activities and constraints but also the value of successor activities and constraints. They assume that all activities and constraints are equally important. They only rely on the number or, at their best, amount of activities and constraints. Further, they solely depend on one criterion to measure the performance of LPS. Furthermore, many of these metrics are incompatible and present no correlation with the overall project performance [3]. The literature review shows no evidence of existing researches that provide a holistic approach to measure the performance of LPS. The aim of this research is to propose a new holistic approach to measure the performance of LPS called valuation. The objectives of this research are: (1) to provide an overview of the current metrics used to measure the performance of LPS, (2) to propose 10 steps to measure the performance of LPS based on the valuation approach, (3) to utilize the valuation approach to derive numerous metrics based on all possible relationships between the main and sub (i.e., activity and constraint) categories of LPS that currently available or may emerge in the future. This research contributes to the body of knowledge by deriving metrics based on the valuation approach that are significantly more comprehensive and mathematically more robust since they integrate several criteria and rely on the value rather than the number or amount of activities or constraints. Hence, the valuation approach generates more accurate results. Moreover, the valuation approach can help the construction professionals to track the performance of LPS across phases or even projects by accumulating the data and measuring the proposed metrics.

2. Literature Review

The LPS is a production planning and control system that utilizes the lean construction philosophy to improve workflow reliability [4]. The LPS has four levels hierarchy of planning, including the Master Plan (MP), Phase Plan (PP), Look-Ahead Plan (LAP) and Weekly Work Plan (WWP). The MP stipulates milestones and key dates [4, 5]. The PP establishes handoffs between trades [6]. The LAP makes tasks ready [4, 7]. The WWP identifies individual assignments and firms commitments [4]. The LPS classifies activities into four main categories, including (1) should: activities that need to be done, (2) can: activities made ready from what should be done, (3) will: activities committed to be done from what can be done, and (4) did: activities completed from what will be done [4]. The following is an overview of the current metrics used to measure the performance of LPS.

Percent Plan Complete (PPC) is the number of activities that have been done with respect to the number of activities that will be done [8].

$$PPC = \frac{Did}{Will} \quad (1)$$

Tasks Anticipated (TA) is the number of activities that will be done with respect to the number of activities that can be done [7].

$$TA = \frac{Will}{Can} \quad (2)$$

Tasks Made Ready (TMR) is the number of activities that have been done with respect to the number of activities that can be done [7].

$$TMR = \frac{Did}{Can} \quad (3)$$

Performance Factor (PF) is the actual productivity with respect to the earned productivity measured in labor hours [9].

$$PF = \frac{Actual\ Labor\ Hours}{Earned\ Labor\ Hours} \quad (4)$$

Labor Utilization Factor (LUF) is the sum of the effective and fourth of the essential contributory work with respect to the sum of the effective, essential contributory, and not useful work [10].

$$LUF = \frac{Effective\ Work + \frac{1}{4} \times Essential\ Contributory\ Work}{Effective\ Work + Essential\ Contributory\ Work + Not\ Useful\ Work} \quad (5)$$

Planned Work Ready (PWR) is the work expected to be performed in LAP with respect to the work that should be performed in LAP [11].

$$PWR = \frac{Work\ Expected\ to\ be\ Performed\ in\ LAP}{Work\ that\ Should\ be\ Performed\ in\ LAP} \quad (6)$$

Delta-1 is the number of constraints promised to be removed with respect to the number of constraints identified [11].

$$\Delta_1 = \frac{Constraints\ Promised\ to\ be\ Removed}{Constraints\ Identified} \quad (7)$$

Delta-2 is the number of constraints removed with respect to the number of constraints promised to be removed [11].

$$\Delta_1 = \frac{Constraints\ Removed}{Constraints\ Promised\ to\ be\ Removed} \quad (8)$$

Delta-3 is the number of new constraints with respect to the number of constraints identified [11].

$$\Delta_1 = \frac{New\ Constraints}{Constraints\ Identified} \quad (9)$$

Percent of Planned Work Completed (PWC) is the average of the amount of completed activities with respect to the amount of planned activities [12].

$$PWC = \frac{\sum_{i=1}^{n}\left(\frac{Amount\ of\ Completed\ Activity_i}{Amount\ of\ Planned\ Activities_i}\right)}{n} \quad (10)$$

Percent of Constraint Removal (PCR) is the number of constraint-free activities when scheduling the WWP with respect to the number of planned activities at the LAP [12].

$$PCR = \frac{Number\ of\ Constraint\ Free\ Activities\ When\ Scheduling\ WWP}{Number\ of\ Planned\ Activities\ at\ LAP} = \frac{Ready}{Can} \quad (11)$$

Project Productivity Index (PPI) is the Average Productivity Index (API). The API is the average labor productivity to the maximum labor productivity [13].

$$PPI = \frac{\sum API}{N} \quad (12)$$

Process Reliability Index (PRI) is the ration of the actual to planned weekly progress of a specific activity [13].

$$PRI = \frac{AP}{PP} \quad (13)$$

Lean Workflow Index (LWI) is a polynomial function that employs several location-based scheduling parameters to describe the workflow, including (A) product of the root mean squares of flowlines, (C) percent of time with no interruptions after finishing a floor, (D) the percent of time squads are working, (E) work in progress, and (F) work out of sequence. A goal-seeking algorithm, based on subjective survey findings of location-based management schedules, was used to measure the weight of parameters [14].

$$LWI(t) = 0.07A^2 + 0.33C^2 + 0.04D^2 + 0.31E^2 + 0.25F^2 \quad (14)$$

Commitment Level (CL) is the number of committed required (critical) activities with respect to the number of activities that should be done [3].

$$CL = \frac{Required\ Will}{Should} \quad (15)$$

Percent Required Completed or Ongoing (PRCO) is the number of required (critical) completed and required ongoing on-track activities with respect to the number of required activities that will be done [3].

$$PRCO = \frac{Required\ Completed + Required\ Ongoning\ on\ Track}{Required\ Will} \quad (16)$$

Milestone Variance (MV) is the difference between the expected and planned completion date of the milestone [3].

$$MV = Expected\ Completion\ Date - Planned\ Completion\ Date \quad (17)$$

Required Level (RL) is the number of required (critical) activities with respect to the number of activities on the WWP [15].

$$RL = \frac{Required\ Will}{Will} \quad (18)$$

Completed Uncommitted (CU) is the work performed that was not included in the WWP with respect to the total activities completed [15].

$$CU = \frac{Excuted - Excuted\ from\ Will}{Did + Backlog + New} \quad (19)$$

$$CU = \frac{Excuted\ from\ Backlog + Excuted\ from\ New}{Did + Backlog + New} \quad (20)$$

Labor Hours Reliability Index (LHRI) is the percent of work completed in terms of labor hours with respect to the total expected labor hours [15].

$$LHRI = \frac{Percent\ of\ Work\ Completed \times Expected\ Labor\ Hours}{Total\ Expected\ Labour\ Hours} \quad (21)$$

Progress Priority (PP) is the aggregated time of the completed activities and their successors with respect to the time of all activities on the WWP that should have been completed and their successors [15].

$$PP = \frac{\sum Time\ Plus\ Sum\ of\ Successors\ Completed}{\sum Time\ Plus\ Sum\ of\ Successors\ of\ WWP\ Should} \quad (22)$$

Other researches tried to combined these metrics into a newly devised planning dashboard [2].

3. Valuation

The valuation is an approach to determine the value, i.e., of an activity or constraint. The performance of a system is measured by the ability of the system to transform entities from a form to another. The valuation approach argues that the metrics used to measure the performance of a system should integrate several criteria and rely on the value of the amount of work from entities that has been transformed from a form to another rather than the number or amount of work of these entities. This is more consistent with the philosophy of lean management. To understand the concept behind the valuation approach, consider the following example. Let us assume that we have six activities from a project represented as balls (see Figure 1). These activities can be classified into several categories based on the status of these activities as they flow in time towards the completion date. Let us only focus on two categories and consider the following scenarios:

We rely on the number of transformed activities from a category to another to measure the performance of the system. In this case, we assume that all activities have the same size of work. In other words, we ignore the size of the activities. For example, we could transform 5 activities from a category to another and then the performance of the system will be almost 83%. However, the size of the last activity may account more than the 5 activities together and therefore the number that represents the performance of the system is misleading.

We rely on the amount of transformed activities from a category to another to measure the performance of the system. In this case, we will overcome the deficiency in our previous case while ignoring a crucial aspect. This aspect is represented by the question of what is the value of the amount of work from entities that has been transformed from a form to another? For example, we could transform 4 activities from a category to another with an amount of 90% of the total amount of work from the whole activities and then the performance of the system will be 90%. However, the last two activities may cost more money, they need more time than the other activities to be transformed, they are more complex, or the completion of many other activities rely on them and they can open more activities to be performed. Consequently, the number that represents the performance of the system is misleading.

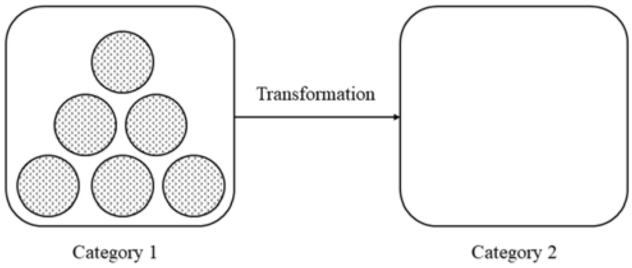

Figure 1. *The transformation process between two categories.*

Accordingly, the following 10 steps are proposed to measure the performance of LPS based on the valuation approach:

Step 1: Determine the main and sub-categories. The main categories can be divided into sub-categories. Likewise, the sub-categories can be divided into sub-sub-categories and so on. The main categories in LPS are Should (S), Can (C), Will (W), and Did (D) [4]. Every main category can be divided into sub-categories Critical (Cr) and Non-Critical (NCr). Every sub-category can be divided into sub-sub-categories Ready (R) and Not Ready (NR). NR can be divided into sub-sub-sub-categories Can be Made Ready (CMR) and Cannot be Made Ready (CNMR). The main categories D and W can additionally have the sub-categories New (N) and Backlog (B) [16]. Every category can be represented as a set of activities or constraints. The constraints are conceived as activities that have similar parameters (i.e., cost and time) with dependency between them. For example, the sets S, C, W, and D containing the activities or constraints $s_1, s_2, \dots, s_n$, $c_1, c_2, \dots, c_n$, $w_1, w_2, \dots, w_n$, and $d_1, d_2, \dots, d_n$ are represented as $S = \{s_1, s_2, \dots, s_n\}$, $C = \{c_1, c_2, \dots, c_n\}$, $W = \{w_1, w_2, \dots, w_n\}$, and $D = \{d_1, d_2, \dots, d_n\}$ respectively, where $D \subseteq W$, $W \subseteq C$, and $C \subseteq S$ iff $x \in D \Rightarrow x \in W \Rightarrow x \in C \Rightarrow x \in S$. The largest category, i.e., S, should be established as the benchmark for calculations.

Step 2: Determine the set of criteria that the activities or constraints need to be evaluated against. There are numerous criteria that can be used to render the various dimensions from which the activities or constraints can be viewed. Although defining these criteria is a crucial step, it appeals more to the art aspect rather than to the science one [17]. There are five standards should be followed when specifying criteria: (1) completeness, (2) decomposability, (3) operationality, (4) non-redundancy, and (5) minimum size [18, 19]. Some of the candidate criteria are cost, duration, quality, safety, risk, complexity, criticality, and dependency. Criticality refers to the probability of an activity or a constraint to lies on the critical path of activities or constraints. Some of the sub-categories, i.e., Cr and NCr, can be eliminated when considering this criterion. Dependency refers to the value of work or constraint that would be available to be performed or eliminated once an activity or a constraint has been partially or fully completed or eliminated. The criteria can be structured in single or multiple levels similar to the Analytical Hierarchy Process (AHP) (see Figure 2) [20, 21]. Psychological researches have demonstrated that most individuals cannot simultaneously compare more than seven items plus or minus two [22]. As a result, it is recommended that the selected criteria to evaluate activities and constraints should not exceed nine.

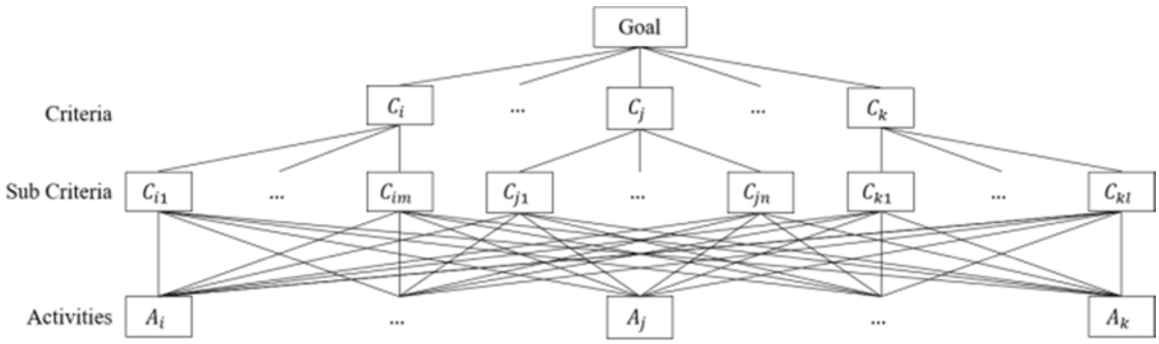

Figure 2. *Analytical Hierarchy Process, adjusted from (Saaty, 1994).*

Step 3: Determine the relative importance, or weight, of these criteria by using the pairwise comparisons [20, 21]. During the pairwise comparison process, the decision makers choose between a set of linguistic phrases, i.e., "*A is more important than B*." Then, they use a scale that maps between the provided linguistic expressions and a set of numbers which depict the importance, or weight, of the former linguistic expressions [17, 23, 24]. The detailed explanation regarding the type of decision maker (single or group), type of data (deterministic, stochastic, fuzzy, or combined), methods used to derive weights (eigenvalue, geometric mean, linear programming, and lambda-max), type of pairwise comparison (proportional or differential), type of scale for quantifying a given set of pairwise comparisons (linear or nonlinear), and methods of adjusting the consistency of wights (i.e., least square method) are out of the scope of this research. For more information about these topics see [17, 23, 24].

Step 4: Determine the valuation matrix (VM). The element a_{ij} indicates the performance of an activity or a constraint A_i that belongs to an $m \times n$ matrix V when it is evaluated in terms of a decision criterion C_j that has a weight of importance ω_j, where $\sum_{j=1}^{n} \omega_j = 1, D \subseteq W \subseteq C \subseteq S \subseteq V$ iff $a_{ij} \in D \Longrightarrow a_{ij} \in W \Longrightarrow a_{ij} \in C \Longrightarrow a_{ij} \in S \Longrightarrow a_{ij} \in V, \forall i \in \{1, 2, \ldots, m\}, \forall j \in \{1, 2, \ldots, n\}$ (see Table 1).

Table 1. *Valuation matrix.*

	C_1	C_2	C_3	…	C_n
ω	ω_1	ω_2	ω_3	…	ω_n
A_1	a_{11}	a_{12}	a_{13}	…	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2n}
A_3	a_{31}	a_{32}	a_{33}	…	a_{3n}
A_m	a_{m1}	a_{m2}	a_{m3}	…	a_{mn}

Step 5: Calculate the relative importance (δ):

$$\delta_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (23)$$

Step 6: Calculate the weighted relative importance (λ):

$$\lambda_{ij} = \delta_{ij} \times \omega_j \quad (24)$$

Step 7: Calculate the aggregated weighted relative importance (ψ):

$$\psi_i = \sum_{j=1}^{n} \lambda_{ij} \quad (25)$$

Step 8: Calculate the percent of amount (ν):

$$\nu_{(X/Y)_i} = \frac{\rho_{X_i}}{\rho_{Y_i}} \quad (26)$$

Where, ρ_{X_i} is the amount of work or constraint that should be, can be, will be, or has been completed or eliminated from an activity or a constraint A_i that belongs to a category X. ρ_{Y_i} is the amount of work or constraint that should be, can be, will be, or has been completed or eliminated from an activity or a constraint A_i that belongs to a category Y. $X \subseteq Y \subseteq V$ iff $A_i \in X \Longrightarrow A_i \in Y \Longrightarrow A_i \in V, \forall i \in \{1, 2, \ldots, m\}$.

Step 9: Calculate the product (φ):

$$\varphi_i = \psi_i \times \nu_{(X/Y)_i} \quad (27)$$

Step 10: Calculate the value (V):

$$V_{X/Y} = \frac{\sum_{k=1}^{l} \varphi_k}{\sum_{p=1}^{q} \varphi_p} \quad (28)$$

Where, l and q are the number of activities or constraints A_k and A_p that belong to categories X and Y respectively, $\forall k = \{1,2, \ldots, l\}, \forall p = \{1,2, \ldots, q\}$.

The possible relationships between the main categories of LPS and the metrics used to measure them are as follows (see Figure 3):

$V_{\mathrm{D/W}}$: the value of work or constraint that has been completed or eliminated with respect to the value of work or constraint that will be completed or eliminated.

$V_{\mathrm{D/C}}$: the value of work or constraint that has been completed or eliminated with respect to the value of work or constraint that can be completed or eliminated.

$V_{\mathrm{D/S}}$: the value of work or constraint that has been completed or eliminated with respect to the value of work or constraint that should be completed or eliminated.

$V_{\mathrm{W/C}}$: the value of work or constraint that will be completed or eliminated with respect to the value of work or constraint that can be completed or eliminated.

$V_{\mathrm{W/S}}$: the value of work or constraint that will be completed or eliminated with respect to the value of work or constraint that should be completed or eliminated.

$V_{\mathrm{C/S}}$: the value of work or constraint that can be completed or eliminated with respect to the value of work or constraint that should be completed or eliminated.

There are six possible relationships between the main categories of LPS. Thus, there are six metrics to measure the performance of LPS in transforming activities or constraints from one category to another.

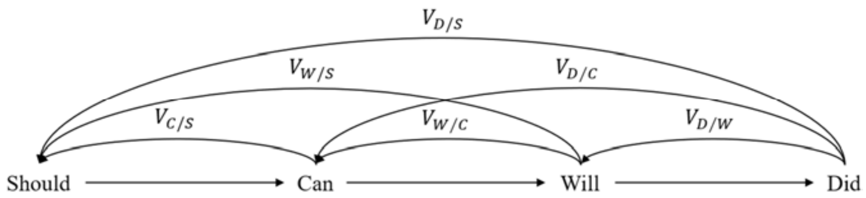

Figure 3. *The possible relationships between the main categories of LPS and the metrics used to measure them.*

Some of the possible relationships between the sub-categories of D and W of LPS and the metrics used to measure them are as follows (see Figure 4):

$V_{D_{Cr}/D}$: the value of critical work or constraint that has been completed or eliminated with respect to the value of work or constraint that has been completed or eliminated.

$V_{D_{NCr}/D}$: the value of non-critical work or constraint that has been completed or eliminated with respect to the value of work or constraint that has been completed or eliminated.

$V_{D_N/D}$: the value of new work or constraint that has been completed or eliminated with respect to the value of work or constraint that has been completed or eliminated.

$V_{D_B/D}$: the value of backlog work or constraint that has been completed or eliminated with respect to the value of work or constraint that has been completed or eliminated.

$V_{W_{Cr}/W}$: the value of critical work or constraint that will be completed or eliminated with respect to the value of work or constraint that will be completed or eliminated.

$V_{W_{NCr}/W}$: the value of non-critical work or constraint that will be completed or eliminated with respect to the value of work or constraint that will be completed or eliminated.

$V_{W_N/W}$: the value of new work or constraint that will be completed or eliminated with respect to the value of work or constraint that will be completed or eliminated.

$V_{\mathrm{W_B/W}}$: the value of backlog work or constraint that will be completed or eliminated with respect to the value of work or constraint that will be completed or eliminated.

$V_{D_{Cr}/W_{Cr}}$: the value of critical work or constraint that has been completed or eliminated with respect to the value of critical work or constraint that will be completed or eliminated.

$V_{D_{NCr}/W_{NCr}}$: the value of non-critical work or constraint that has been completed or eliminated with respect to the value of non-critical work or constraint that will be completed or eliminated.

V_{D_N/W_N}: the value of new work or constraint that has been completed or eliminated with respect to the value of new work or constraint that will be completed or eliminated.

V_{D_B/W_B}: the value of backlog work or constraint that has been completed or eliminated with respect to the value of backlog work or constraint that will be completed or eliminated.

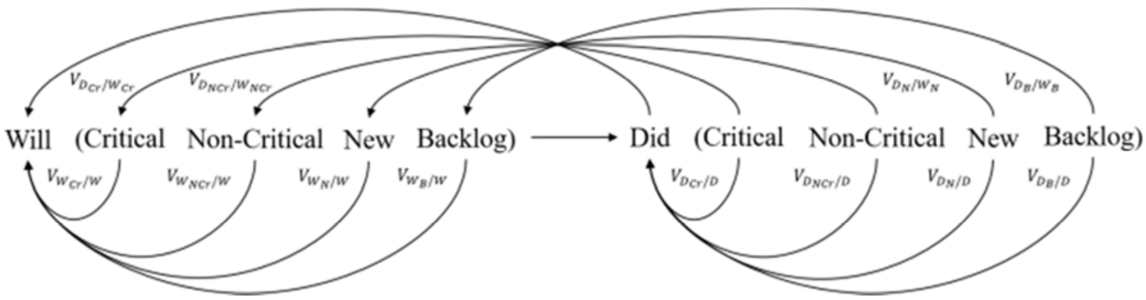

Figure 4. *The possible relationships between the sub-categories of D and W of LPS and the metrics used to measure them.*

These are 12 possible relationships between the sub-categories of D and W of LPS. There are four metrics to measure the performance of LPS in transforming activities or constraints from the sub-categories of W to the sub-categories D. There are eight metrics to measure the values of sub-categories with respect to the main categories of D and W. The metric $V_{W_N/W}$ can be used to measure the performance of LPS in breaking down activities or identifing constraints. Similarly, the valuation approach can be utilized to derive numerous metrics based on all possible relationships between the main and sub (i.e., activity and constraint) categories of LPS that currently available or may emerge in the future. Although some of the derived metrics are to some extent similar to the current metrics, they are significantly more comprehensive and mathematically more robust since they integrate several criteria and rely on the value rather than the number or amount of activities or constraints.

A numerical example

To calculate the metrics required to measure the performance of LPS in transforming activities from one category to another, consider the following steps (see Tables 2-5):

Step 1: The main categories are S, C, W, and D, where $D \subseteq W$, $W \subseteq C$, and $C \subseteq S$ iff $x \in D \Longrightarrow x \in W \Longrightarrow x \in C \Longrightarrow x \in S$. The largest category S has been established as the benchmark for calculations.

Step 2: The set of criteria that the activities need to be evaluated against are four single level criteria, $C = \{c_1, c_2, c_3, c_4\}$.

Step 3: These criteria, after pairwise comparison, have been assigned weights of importance from the perspective of a decision maker, $\omega = \{0.1, 0.4, 0.2, 0.3\}$, where $\sum_{j=1}^{n} \omega_j = 1, \forall j \in \{1,2,3,4\}$.

Step 4: The element a_{ij} indicates the performance of an activity A_i that belongs to a 6×4 matrix V when it is evaluated in terms of a decision criterion C_j that has a weight of ω_j, where $\sum_{j=1}^{n} \omega_j = 1, D \subseteq W \subseteq C \subseteq S \subseteq V$ iff $a_{ij} \in D \Longrightarrow a_{ij} \in W \Longrightarrow a_{ij} \in C \Longrightarrow a_{ij} \in S \Longrightarrow a_{ij} \in V, \forall i \in \{1,2,3,4,5,6\}, \forall j \in \{1,2,3,4\}$. These values, in this example, were generated randomly.

Step 5-10: A sample calculation is provided for these steps. The numbers were rounded to two decimal places.

Table 2. *Valuation matrix (VM).*

	C_1	C_2	C_3	C_4
ω	0.1	0.4	0.2	0.3
A_1	60	38	45	36
A_2	65	52	39	80
A_3	98	74	65	27
A_4	95	23	100	78
A_5	59	63	48	43
A_6	100	30	22	75
Sum	477	280	319	339

Table 3. *Relative importance (δ).*

	C_1	C_2	C_3	C_4
ω	0.1	0.4	0.2	0.3
A_1	0.13	0.14	0.14	0.11
A_2	0.14	0.19	0.12	0.24
A_3	0.21	0.26	0.20	0.08
A_4	0.20	0.08	0.31	0.23
A_5	0.12	0.23	0.15	0.13
A_6	0.21	0.11	0.07	0.22

Table 4. *Weighted relative importance (λ).*

	C_1	C_2	C_3	C_4
ω	0.1	0.4	0.2	0.3
A_1	0.01	0.05	0.03	0.03
A_2	0.01	0.07	0.02	0.07
A_3	0.02	0.11	0.04	0.02
A_4	0.02	0.03	0.06	0.07
A_5	0.01	0.09	0.03	0.04
A_6	0.02	0.04	0.01	0.07

Table 5. *Aggregated weighted relative importance (ψ), percent of amount (ν), and value (V).*

	ψ	$\nu_{C/S}$	$\nu_{W/C}$	$\nu_{D/W}$	V	
A_1	0.13	1	1	1	CS	77%
A_2	0.18	1	1	0.9	WS	55%
A_3	0.19	0.9	0.8	0.8	DS	40%
A_4	0.18	0.8	0.7	0	WC	72%
A_5	0.17	0.8	0	0	DC	52%
A_6	0.14	0	0	0	DW	73%

$$\delta_{31} = \frac{a_{31}}{\sum_{i=1}^{6} a_{31}} = \frac{98}{60+65+98+95+59+100} = 0.21$$

$$\lambda_{31} = \delta_{31} \times \omega_1 = 0.21 \times 0.1 = 0.02$$

$$\psi_3 = \sum_{j=1}^{4} \lambda_{3j} = 0.02 + 0.11 + 0.04 + 0.02 = 0.19$$

$$\nu_{(D/S)_3} = \frac{\rho_{D_3}}{\rho_{S_3}} = \frac{\rho_{D_3}}{\rho_{W_3}} \times \frac{\rho_{W_3}}{\rho_{C_3}} \times \frac{\rho_{C_3}}{\rho_{S_3}} = 0.8 \times 0.8 \times 0.9 = 0.58$$

Where, $\nu_{(D/S)_3}$ is the amount of work that has been done from A_3 with respect to the amount of work that should be done from A_3. The values of ν, in this example, were assigned arbitrarily.

$$\varphi_3 = \psi_3 \times \nu_{(D/S)_3} = 0.19 \times 0.58 = 0.11$$

$$V_{D/S} = \frac{\sum_{k=1}^{3} \varphi_k}{\sum_{p=1}^{6} \varphi_p} = \frac{0.13+0.16+0.11}{1} = 40\%$$

Hence, the value of work that has been done with respect to the value of work that should be done is 40%. To calculate the value of critical work that can be completed from the sub-category $Cr = \{A_1, A_2, A_3\}$ with respect to the value of work that can be completed from the main category $C = \{A_1, A_2, A_3, A_4, A_5\}$.

$$V_{C_{Cr}/C} = \frac{\sum_{k=1}^{3} \varphi_k}{\sum_{p=1}^{5} \varphi_p} = \frac{0.13+0.18+0.17}{0.13+0.18+0.17+0.15+0.14}$$

$$= \frac{0.48}{0.77} = 63\%$$

Hence, the value of critical work that can be done with respect to the value of work that can be done is 63%. The other metrics can be calculated in the same way. It should be noticed that $V_{D/W}$, $V_{W/C}$, and $V_{D/C}$ are the corresponding metrics to PPC, TA, and TMR respectively. However, the derived metrics are significantly more comprehensive and mathematically more robust since they integrate several criteria and rely on the value rather than the number or amount of activities or constraints. Relying on $V_{D/W}$ to measure the overall performance of LPS is misleading since this metric only measures the performance of LPS in transforming activities or constraints from W to D. Consequently, the focus should be directed towards $V_{D/S}$ since this metric is the true reflection of the overall performance of LPS. Thus, the efforts should be exerted to increase its value.

4. Conclusion

This research is one of the pioneering researches that proposes a new holistic approach to measure the performance of LPS called valuation. Valuation is an approach to determine the value, i.e., of an activity or constraint. 10 steps were proposed to measure the performance of LPS based on the valuation approach. The valuation approach can be utilized to derive numerous metrics based on all possible relationships between the main and sub (i.e., activity and constraint) categories of LPS that currently available or may emerge in the future. The metrics derived based on the valuation approach are significantly more comprehensive and mathematically more robust since they integrate several criteria and rely on the value rather than the number or amount of activities or constraints. Hence, the valuation approach generates more accurate results. Moreover, the valuation approach can help the construction professionals to track the performance of LPS across phases or even projects by accumulating the data and measuring the proposed metrics. The author recommends the following as future researches: (1) Evaluating the efficiency of the valuation approach in measuring the performance of LPS through simulation and real-life projects. This can be done through measuring the correlation between the obtain results from applying the valuation approach against the actual overall project performance and comparing them against the conventional metrics. (2) Employing the valuation approach in measuring the performance of other systems. (3) Developing a software program that can integrate the valuation approach in the planning and control process of projects.

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