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PROJECT WIP MANAGEMENT AS A RISK CONTROL DRIVER FOR TIMELY COMPLETION

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ABSTRACT

This research addresses a critical gap in construction management by introducing novel indicators for assessing completion through Work-In-Process (WIP) management. The study reveals that project production management practitioners frequently equate physical progress with completion, a misconception contributing to unexpected project delays. Through production systems patterns analysis, this research introduces Rate of WIP (R_{WIP}), Rate of Completion Convergence (R_{CC}), and complementary metrics for multiple production systems completion (Q6) and maximum achievable completion (Q6'). These indicators, grounded in Little's Law principles, provide a framework for monitoring completion trends and predicting schedule overruns. The methodology combines modeling with practitioner surveys, demonstrating how WIP patterns serve as early warning signals for potential delays for unstable production systems, enabling proactive schedule risk management and improved project delivery reliability.

KEYWORDS

WIP, completion, progress, 90% syndrome, early warning.

INTRODUCTION

This paper introduces a novel approach to assess completion using WIP indicators. The author argues that a key source of confusion in project timelines stems from conflating completion with progress. Later, an equation demonstrates that completion is not equivalent to progress—instead, it is merely one component of it. Two poll results on completion and WIP assessment reveal practitioner bias leading to omission of proper completion trend analysis. Failing to achieve timely completion results in the 90% Syndrome. Ford & Sterman (2003) from MIT analyzed this in "Overcoming the 90% Syndrome: Iteration Management in Concurrent Development Projects," using System Dynamics to obtain a completion curve for the whole scope. The current approach to Little's Law for construction aims to achieve proper WIP where throughput (TH) reaches optimal levels for specific systems. The author proposes an application extension for assessing completion through WIP management across multiple production systems which might not be controllable and stable. This approach allows R_{WIP}, R_{CC}, Q6 and Q6' trend analysis to reveal project completion performance while identifying plateaus in completion curves where TH equals 0. The paper suggests that Takt Time Planning (TTP) and Last Planner® System (LPS) have limitations in managing WIP and assessing completion across multiple production systems within a single project. TTP assumes deterministic completion of

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trade activities, yet outcomes are probabilistic, with deliverables either acceptable (completed) or non-acceptable (WIP). Non-acceptable results often require rework. Here, indicators like R_{WIP}, R_{CC}, Q6, and Q6' help monitor TTP outcomes by linking WIP to deliverable states.

PURPOSE

The purpose of this theoretical study is to propose a way to assess completion using novel indicators based on WIP and completion values, all of this working as an early warning for preventing unexpected project delays while, apparently, completion is close; all of this denoting the existence of the 90% Syndrome in project completion. Likewise, the study presents how this is related to Little's Law approach and aims to serve as a foundation for future research.

LITERATURE REVIEW AND FOUNDATIONS

WIP is an inherent component of production system studies, involving strategic constraint management to expedite task completion. In manufacturing, WIP represents inventory, a form of waste (Ohno, 1988). WIP can be measured as unprocessed off-site manufactured units for each trade across production phases (Faloughi et al., 2015). In construction, Gharaie et al. (2012) defined WIP as projects under construction, with processing time represented by average house completion time (AHCT). Although not explicitly stated, WIP functions as a state of things while typically defined as part of a production system. Regarding WIP limits, Hopp and Spearman (2000) conceptualized CONWIP as a pull production system maintaining constant, fixed WIP limits across entire production lines. Jang and Kim's (2007) Percent of Constraint Removal (PCR) method offers systematic WIP management by eliminating barriers impeding progress. Emdanat et al. (2016) proposed Percent Required Completed or Ongoing (PRCO), evaluating percentage of required activities completed by promised dates, including ongoing activities projected for completion. They introduced Milestone Variance (MV), denoting the gap between anticipated completion dates for remaining tasks and milestone deadlines. Although remaining activities aren't clearly defined as excluding ongoing ones, this highlights activities in Not-Started state, which with WIP and Completion will later define the scope equation. Monitoring these states prevents the 90% Syndrome; as states evolve sequentially, they define the completion dead zone—the period from site works commencement until first deliverable completion. Regarding constraints, Abdelhamid et al. (2010) demonstrated relationships between production constraints and workflow reliability, identifying planning failures preventing work commencement, requiring constraint assessment for Not-Started states. Except for Gharaie's AHCT, which assesses single housing unit project completion, LPS metrics primarily focus on workflow efficiency. For whole project completion evaluation, Earned Value Method (EVM) metrics like Cost Performance Index (CPI) or Schedule Performance Index (SPI) can complement. However, EVM measures the entire scope, simultaneously including WIP and completed elements, offering no exclusive completion assessment per deliverable. This aligns with the need for practical constraint assessment approaches supporting timely completion based on requirement (specification) achievement, describing deliverable characteristics rather than relying solely on quantity estimations.

METHODOLOGY

The methodology for this study follows a structured approach: **observation and hypothesis** development regarding project production management practitioners' understanding of key concepts; **assessment of key concept understanding** through directed polls on completion and WIP definitions with construction professionals of varying experience levels; **completion analysis** based on mutual exclusive deliverables' states; **WIP metrics definition** based on literature and completion analysis; **constraints analysis** examining physical, logical, and resource factors affecting work progression; simulation of proposed metrics and related equations under different project conditions and **discussion** integrating novel indicators with established systems like TTP and LPS.

OBSERVATION AND HYPOTHESIS

In Peru, construction management practitioners commonly assess project progress as if it were equal to completion, missing the fact that completion means there is no more work to do with respect to deliverable physical conformation, which represents the final production system outcome, and factually omitting the effect of WIP inherent to project progress estimates.

ASSESSMENT OF KEY CONCEPTS UNDERSTANDING

Poll Results on WIP and Completion Understanding

There is a prevalent bias toward considering project progress (P6) estimates as the way for assessing completion; indeed, as will be shown in the relevant poll, progress is wrongly taken as equal to completion. Figure 1 shows the answers for one concerning question: *If your project is at 90% physical progress (well calculated), what percentage remains to reach 100% completion?* Only 22% of respondents selected the right answer. As it will be shown in the Completion Analysis section, the correct answer is "can't be determined," as WIP data is needed to estimate completion from a given P6 value.

Table 1: Survey specs on completion understanding

Location	Peru	**% Peru responders**	100.0%
Size	45	**% other countries**	0%
Mean	Online poll	**Dates**	Oct 2021; Jul 2024; Jan 2025
Tool	Google Forms	**Source**	Database built in Peru
Type	In-Program Polling	**Target**	Construction Mgmt Practitioners

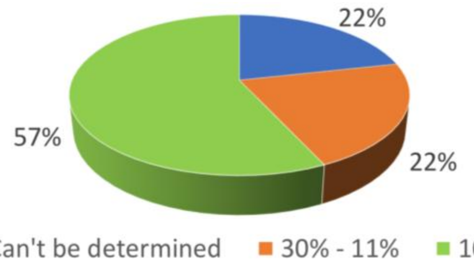

Figure 1: Answers to poll on completion understanding

Another poll was conducted to assess WIP understanding. The poll presented the logical outcomes for every activity: deliverables completed due to meeting requirements only. Respondents showed bias by assuming activity completion automatically meant deliverable completion, whether requirements are met or not. The poll's question was: *There are 10 concrete slabs to be poured in week "n". At the end of week "n" activities, 7 slabs were concrete poured on the scheduled dates. 1 slab had no work done on it, and 2 slabs had their reinforcement, formwork, and embeds ready and authorized for concrete pouring in the following week "n+1". Of the 7 slabs that were poured, 3 have minor defects that require 10% of time/resources for repairs. How many slabs remain in Work-In-Process (WIP) state at the end of week "n"?* Only 35.85% selected the correct answer of 5 slabs in WIP state: 2 slabs with pending work plus 3 slabs with defects. The defective slabs cannot achieve completion state and must remain in WIP because there is pending work to achieve completion as defined above. Some respondents assumed the slab with no work as WIP, which is a contradiction.

Table 2: Survey specs on WIP understanding

Location	Peru	**% Peru responders**	86.8%
Size	53	**% other countries**	13.2%
Mean	Online Poll	**Date(s)**	Jan 2025
Tool	Google Forms	**Source**	Database built in Peru
Type	Construction Social Network	**Target**	Construction Mgmt Practitioners

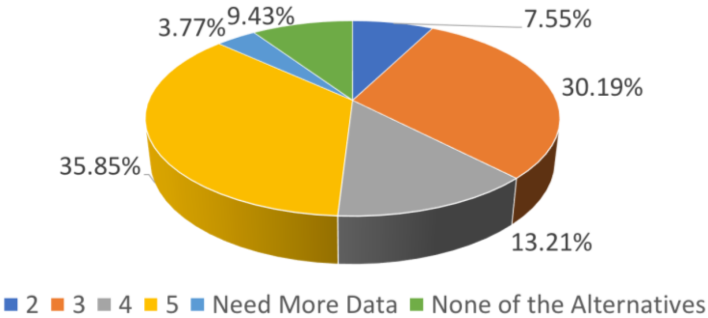

Figure 2: Answers to poll on WIP understanding

Although the samples' size is statistically not representative and needs to be increased, these results are very consistent with the hypothesis that, in Peru, there might not be a clear understanding of what completion, progress, and WIP are, which may imply difficulties in proper use of modern construction approaches based on these parameters. A larger survey showing similar patterns would indicate most practitioners fail to properly analyze activity results, leading to incorrect assumptions about completion and WIP.

COMPLETION ANALYSIS

LPS framework doesn't delve into the fact that activity finalization has two possible outcomes—meeting requirements or not. However, in LPS literature, *activity completion* can be interpreted as valid only if the outcome meets specified requirements, as part of the value creation process (Ballard, 2000). Activity outcomes are measured through progress (P6) curves using methods like earned value (PMI, 2017). EVM cannot identify the 90% Syndrome as it measures all work, including both WIP and completed elements. Focusing on deliverables, each exists in one of three exclusive states: Not-Started (ns), Work-In-Process (wip), or Completed (ok). With K total deliverables in scope, these can be expressed as:

$$\sum ns + \sum wip + \sum ok = K$$

This unveils the principle that the sum of all deliverables' completion states equals the total number of deliverables within a given scope. Using uppercase and Q6 as the nomenclature for "ok" in terms of percentage expressions, we define the scope equation as follows:

$$NS + WIP + Q6 = 1$$

On the other hand, P6 estimates include both completed and WIP deliverables. Here, the latter is affected by individual factors (*f*) since each deliverable has different stages of conformation due to different trade-activities status. Thus, P6 is defined by the following equation (in Figure 3, P6 equals 0.74).

$$P6 = \frac{\sum f * wip}{K} + \frac{\sum ok}{K}$$

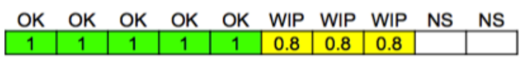

Figure 3: Graphic representation of progress

In Figure 3, if the project never transitions Not-Started deliverables (white squares) into the Work-In-Process state, the maximum completion value is the sum of current completed deliverables (ok) and the number of Work-In-Process deliverables. This is referred to as Q6':

$$Q6' = Q6 + WIP$$

During project execution, two patterns can be observed for completion states. The first pattern is shown in Figure 4, where Not-Started states remains constant. As Q6 increases, the rate of completed elements is expected to decelerate after month n+1, as there is no room for further completion which depends on pre-existing WIP. This pattern highlights the "student syndrome," characterized by a lack of urgency to start (Goldratt, 1997), which in this case means no urgency in transitioning Not-Started deliverables into Work-In-Process. It is important to note that, in this scenario, Q6' always predicts the upper limit for Q6.

Figure 4: Completion evolution pattern #1

The second pattern (see Figure 5) is likely most common in project execution, where WIP experiences uncontrolled increase. Combined with standard P6 estimates being based on quantities and/or related activities, the associated monetary income for progress is assumed as third-party fair validation of completion, having P6 incorrectly equated with completion.

Figure 5: Completion evolution pattern #2

WIP METRICS DEFINITION

Rwip and Rcc

The aforementioned approach is in conjunction with Little's Law, where WIP=TH* CycleTime (Little, 1961). Here, Q6 is equal to the throughput (TH) over a given specific period for the entire project production system. Additionally, Q6 can be interpreted as the cumulative departures per Little's Law literature if Q6 is used for a single production system. Q6' represents cumulative arrivals, as graphically developed by Little and Graves (2008), where the necessary convergence to 100% scope at the true completion date is apparent. To reduce the risk of failing to complete the project on time, a trend assessment based on Q6 and Q6' convergence is necessary, using well-known regression analysis in conjunction with the scope equation described above. Additionally, we define the rate of WIP performance (R_{WIP}) as an initial metric for assessing Q6 and Q6' trends toward true completion. As WIP equals Q6' minus Q6, faster project-wide WIP reduction indicates earlier initiation of completion. This metric illustrates WIP behavior over time:

$$R_{WIP} = \frac{WIP_t}{WIP_{t-1}}$$

If completion is originally required by the project contract to occur at time t_c, and R_{WIP} approaches t_c without decreasing, even though P6 (progress) is on track or above, it will reveal a 90% Syndrome condition. R_{WIP} equals 0 either when the pattern trend in Figure 4 emerges, leaving remaining scope in the Not-Started state, or when the project achieves full completion. In this line, we define the rate of completion convergence (R_{CC}) to monitor the alignment of Q6 and Q6' as they approach completion, which occurs when R_{CC} equals 0.

$$R_{CC} = R_{WIP} + NS$$

Constraint Analysis

The constraint analysis will focus on increasing completion (Q6) by reducing its plateaus. To achieve this, we propose the constraint matrix described in Figure 6, which maps different constraint stages. This mapping highlights the root causes of plateaus to address enabling R_{WIP} to decrease. The matrix's upper row represents two completion states and Not-Yet-Delivered (ok'). Also, the 3x3 matrix identifies three groups of constraints: internal constraints (ic), external constraints (ec), and technical wait time (twt). Not-Yet-Delivered signifies that completion has been achieved but handover has not occurred. This state reflects that deliverables may not face technical constraints (removing the applicability of technical wait time), but rather issues related to paperwork, management certifications, or corporate bureaucracy. To utilize this matrix, the assessment must adopt a one-party perspective, e.g., the contractor. If the contractor cannot complete a deliverable that remains in Work-In-Process, it could be due to (a) the contractor's sole responsibility, (b) also the client's failure to provide remaining access required to complete the work, or (c) no party's responsibility, as the deliverable is subject to inherent technical waiting time (e.g., concrete curing).

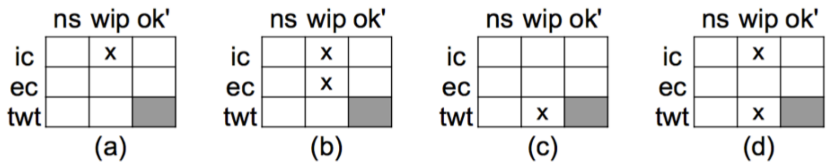

Figure 6: Constraint matrix examples

RESULTS

WIP in Stable Production Systems

In a typical production system, the goal is to maintain WIP at a constant level such that TH reaches its maximum value. Increasing WIP beyond this point is unnecessary, as TH remains constant. For a system with three stations, where process durations are 20, 30, and 40 time-units, Figure 7 illustrates a common representation of a stable production system, showing the progression as deliverables in the Not-Started state transition to Work-In-Process and then to completion. Here, WIP remains constant except at the start and end of the process, causing Q6 and Q6' to run mostly parallel. The accepted conclusion is to control WIP to maximize TH, in line with the principle of flow conservation (Little, 2008), a key objective in the manufacturing industry.

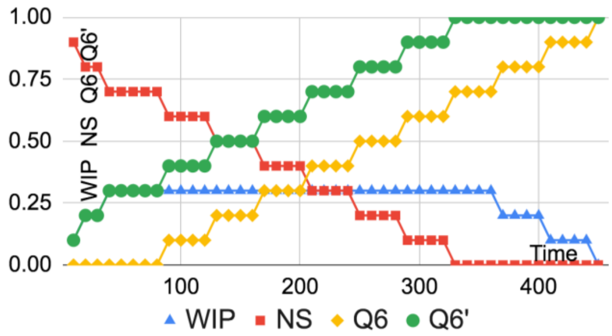

Figure 7: Graphic evolution of completion states with stable WIP

The author agrees with this approach but notes that maintaining constant WIP across multiple, variable production systems is unrealistic, risking project deadlines. To address this, the paper proposes indicators and methods for assessing completion, focusing on the completion date as a critical milestone.

WIP PATTERNS IN UNSTABLE PRODUCTION SYSTEMS

Figure 8 illustrates completion pattern #1 including stations Sa, Sb, and Sc for each deliverable.

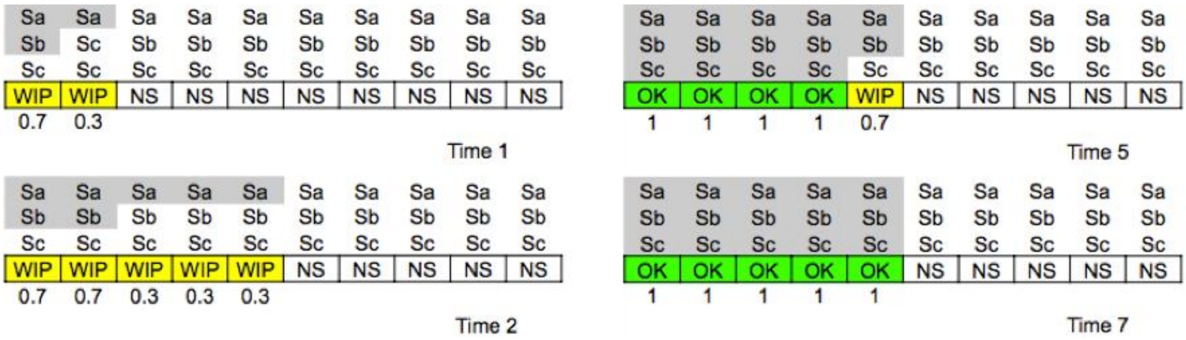

Figure 8: Completion pattern #1 and concerning workstations

In Figure 9, Q6 rises but stalls, preventing completion without additional WIP. This pattern also occurs in projects requiring all WIP deliverables be finished per termination agreements, as in construction open work areas (Haronian & Korb, 2023).

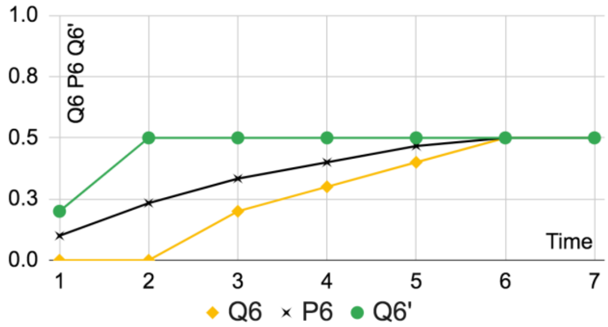

Figure 9: Completion pattern #1 curves

Figure 10 depicts completion pattern #2, which also includes stations Sa, Sb, and Sc. In this case, WIP is increased causing P6 to peak initially. This effort is based on the erroneous assumption that P6 equals Q6 (completion). However, this approach fails to increase actual completion, as two deliverables remain in the Work-In-Process state.

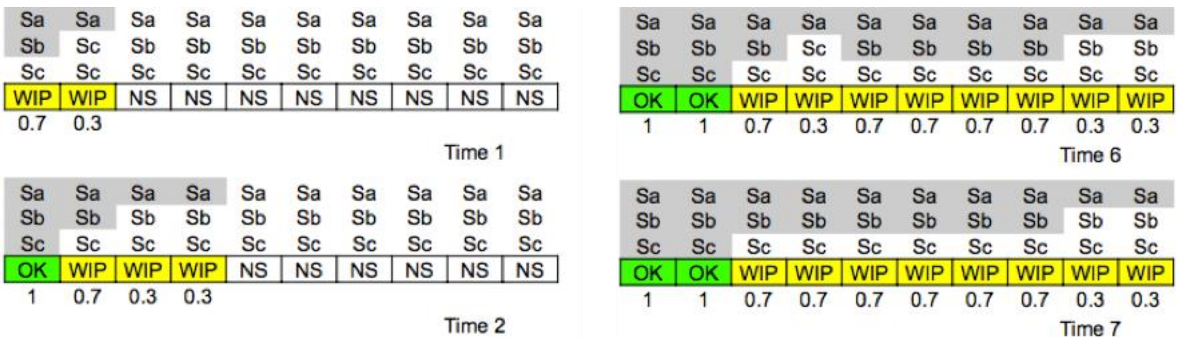

Figure 10: Completion pattern #2 and concerning workstations

Figure 11 illustrates the evolution of pattern #2. P6 growth depends on Q6', which increases but eventually stalls due to the lack of remaining scope for new WIP. Completion becomes compromised because the time required to transition WIP to completion (Q6) may not suffice. A critical scenario arises if P6 is close to 100% while Q6 remains significantly lower, leading to a 90% Syndrome condition where P6 struggles to achieve true completion.

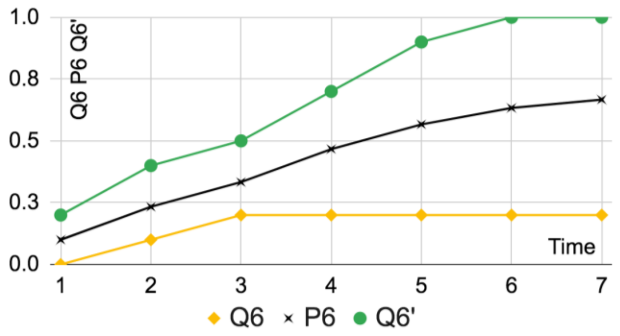

Figure 11: Completion pattern #2 curves

WIP ANALYSIS FOR COMPLETION

Figure 12 presents a variation of the case shown in Figure 7, now incorporating extended waiting times and/or variations in workstation durations. In this case, Q6 and Q6' diverge initially and eventually converge when Q6' reaches 100%. For simplicity, Q6 is shown as linear in this example, though in real-world conditions it is not, as TH is not always constant. However, the averaged slope of Q6 between two points represents the TH during that period.

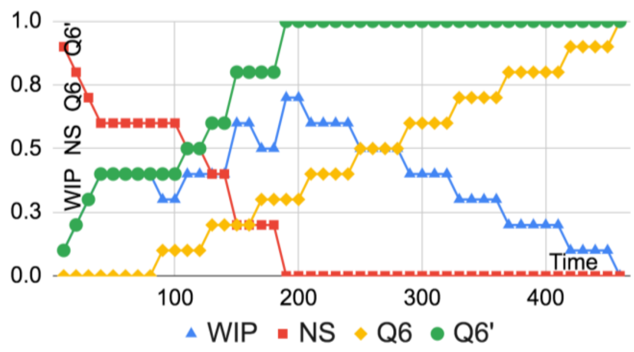

Figure 12: Graphic evolution of completion states with unstable WIP

Reducing undesirable WIP growth is a standard practice aimed at achieving optimal TH. This approach requires a granular focus on each production system. While necessary, it is an indirect method of managing WIP for all work packages to ensure on-time project completion. In this context, visual representations of construction schedules that enable planners to identify WIP are beneficial (Faloughi et al., 2015). Two specific actions can be taken: managing completion plateaus and addressing completion convergence. Figure 13 illustrates Q6 and Q6' resulting from a pattern between patterns #1 and #2 shown in Figures 9 and 11. The P6 metric demonstrates temporal stability approaching completion (Time 10) but Q6 reveals a plateau from Time 4 to Time 6. Failing to distinguish between P6 and Q6 obscures plateau recognition, preventing timely intervention to assure completion.

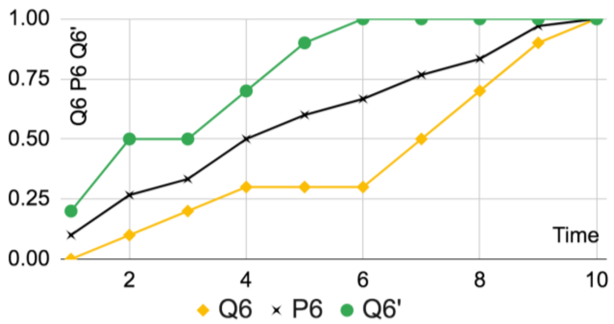

Figure 13: Completion curves for mixed completion patterns

To assess completion, we use R_{WIP} and R_{CC}, along with traditional regression analysis of Q6 and Q6', to estimate the completion date. Figure 14 presents the values of these rates for assessing proximity to completion. Furthermore, Figure 15 illustrates the evolution of Not-Started, Q6, and Q6' based on the scope equation.

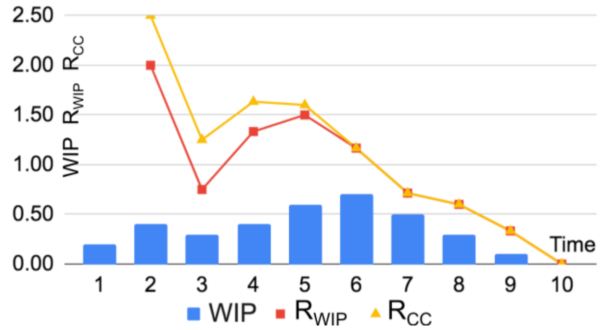

Figure 14: WIP, R_{WIP}, R_{CC} evolution in mixed patterns

It is worth noting that the principle of mutually exclusive completion states allows for understanding granular completion evolution as discrete leaps. This principle may enable further statistical analysis using methods such as Markov Chain Analysis, where completion is represented as an absorbing state. This is evident in Figures 8 and 10, where the Not-Started state can persist or transition to WIP, which in turn can persist or transition to completion.

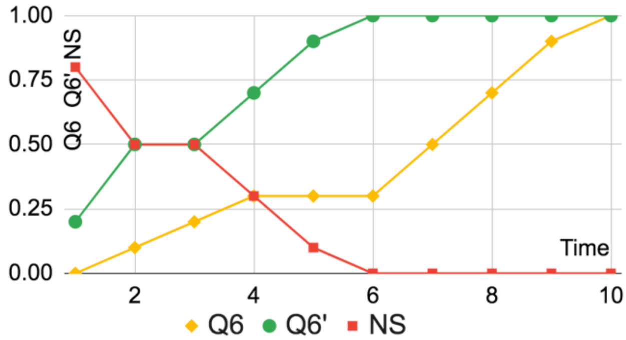

Figure 15: Scope equation results for mixed patterns

DISCUSSION

Takt Time Planning, resulting in takt visualization tools such as trade flows, is designed and monitored under the factual assumption that the result of finishing one trade activity has one deterministic acceptable outcome, meaning completion. However, the truth is that the acceptable result is probabilistic, as results naturally have two possible mutually exclusive outcomes: acceptable or not acceptable. Only completion is acceptable, as completion is based on fulfilling requirements. Thus, the multiple results of different and simultaneous trade activities in multiple production systems on site include a percentage of non-acceptable outputs, which are indeed WIP outputs, as they are neither not-started nor completed. Given the three possible deliverable states previously mentioned, the negation of two states defines the final state of a given deliverable. WIP is supposedly reduced through proper TTP as part of LPS approach, but as explained, there is inherent resulting WIP when finishing activities as part of TTP ground execution. Since completion is only achieved with acceptable results, WIP remains when non-acceptable results arise. Thus, as the presented indicators—R_{WIP}, R_{CC}, Q6, and Q6'—are connected to WIP, which is a key element of TTP, and are further linked to the novel deliverable states of Not-Started and Completed; they provide a framework for monitoring the real outcomes of TTP execution in relation to the completion of the scope of work.

Finally, should the project actively use the LPS and Location-Based Management System (LBMS), there is a clear path to implementing these deliverable-state approach indicators. This is because LBMS sectorization groups deliverables, and since this approach focuses on tracking deliverable completion, it functions as a summary of trade-activity completed outcome balance. Additionally, it represents the delivery readiness of a facility by accounting for the non-deterministic outcomes of the entire finished activity.

SITE RESEARCH PROJECT

The starting points for this study are observations described in this paper regarding misconceptions among project production practitioners in Peru about completion and WIP. Extended research could strengthen these observations by: (1) Conducting broader surveys on the concepts presented in this paper; (2) Organizing focus groups with both senior and junior LPS practitioners; (3) Reviewing WIP estimates in active projects. Regarding the proposed new metrics, site validation experiments should consider the following: (1) Conducting experiments in ten building projects (towers); (2) Involving senior LPS practitioners in the selected projects; (3) Recording new indicators daily for a period of two months and applied to selected trades.

CONCLUSIONS

This study introduces a new approach to assessing WIP in unstable production systems within a project, focusing on the key objective for project parties: meeting the completion due date. For doing this, it sets a distinction between progress (P6) and actual completion (Q6). While the traditional approach to managing undesired WIP increases starts by analyzing the stability of every single system, the approach presented here begins with assessing the completion due date, identifying completion plateaus as risk's early warnings, and then prioritizing the delivery process through constraint analysis.

New metrics, R_{WIP} and R_{CC}, are introduced, along with Q6 and Q6', which represent the cumulative arrivals and departures of multiple systems in a single project. The study shifts the focus from activity completion to deliverable completion. The consistent, though limited, results from the surveys offer insights for future research on WIP estimates and decision-making processes related to achieving completion. Accordingly, a research project is proposed to strengthen the findings on completion and WIP understanding.

In this development, simulations were conducted on delimited process models for both stable and unstable systems, showing variations in R_{WIP} and R_{CC}. The results demonstrate how R_{WIP} increases when risky divergence arises between Q6 and Q6', indicating that completion is at risk. R_{CC}, on the other hand, trends toward zero as systems approach full completion. Furthermore, due to the mutually exclusive principle of completion states—Not-Started, Work-In-Process, and Completion—the study suggests exploring statistical analyses such as Markov Chain Analysis, which could provide insights into the potential behavior of WIP across multiple systems until scope completion. Finally, the study lays the groundwork for further research and on-site validation to refine and expand the application of these novel metrics.

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