MODELING MEASURES OF RISK CORRELATION FOR QUANTITATIVE FLOAT MANAGEMENT OF CONSTRUCTION PROJECTS

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ABSTRACT: Risk exists in all construction projects and resides among the collection of subcontractors and their array of individual activities. Wherever risk resides, the interrelation of participants to one another becomes paramount for the way in which risk is measured. Inherent risk becomes recognizable and quantifiable within network schedules in the form of consuming float – the flexibility to absorb delays. Allocating, owning, valuing, and expending such float in network schedules has been debated since the inception of the critical path method itself.

This research investigates the foundational element of a three-part approach that examines how float can be traded as a commodity, a concept whose promise remains unfulfilled for lack of a holistic approach. The Capital Asset Pricing Model (CAPM) of financial portfolio theory, which describes the relationship between risk and expected return of individual stocks, is explored as an analogy to quantify the inherent risk of the participants in construction projects. The inherent relationship between them and their impact on overall schedule performance, defined as schedule risk –the likelihood of failing to meet schedule plans and the effect of such failure, is matched with the use of CAPM's beta component – the risk correlation measure of an individual stock to that of the entire market – to determine parallels with respect to the inner workings and risks represented by each entity or activity within a schedule. This correlation is the initial theoretical extension that is required to identify where risk resides within construction projects, allocate and commoditize it, and achieve actual tradability.

Keywords: Scheduling; Risk; Float; Valuation; Correlation, Beta

1. INTRODUCTION

Construction managers are tasked with planning and controlling all aspects of their projects, both technical and non-technical. The primary dimensions of these temporary endeavors that are created by expending resources [1] are time and cost. They are highly interrelated [2] under the desired scope of the project and are subject to constraints. Project management seeks to deliver projects safely, on schedule, within budget, and to the desired specifications, based on the best data, conscious of known and unforeseen risks, and prepared to mitigate them as they occur.

To accomplish this, contemporary project management has an abundance of analytical tools at their disposal. Among them and ubiquitous in its use across the construction industry [3] is the critical path method of scheduling (CPM). When properly initiated and updated, CPM application provides managers with a wealth of information regarding the sequence of work, current status, the potential to meet the as-planned duration, and manage the cadre of activities and subcontractors.

Regrettably, most project planning is carried out in the planner's mind or by ad-hoc methods [4] [5], and relies on planners' intuition, imagination, and judgment [6]–[9]. But knowledge and experience remain insufficient to ensure project success [10].

Similarly, on the opposite end of the project, when these temporary endeavors ceases to expend time and resources, when risks and uncertainty have been overcome, schedule analytics become mute and there is no "living" indicator correlating individual activities (subcontractor) to the collective project (general contractor) track record for success and the potential of this as an indicator of future performance.

Such an indicator characterizing schedule performance, the measure of the actual completion time versus that planned, is missing from the construction industry. The indication of contractor and subcontractor production efficiency, organizational maturity, competitiveness, and ultimately their collective and individual abilities to complete work in a timely manner as originally conceived, is seldom considered after completion of the work and rarely evaluated as an indication of future success. This is due to the competitive bidding process being price-focused (to acquire the next job), and more importantly because no universal historical measures have been applied to schedule performance.

There is a multiplicity of sources focused on pricing and acquisition measures (e.g., R.S. Means *Building Construction Cost Data*), while no information exists to benchmarking the collective performance of individual contractors with respect to historic (and by extension predictive) schedule fulfillment. Cost and productivity statistics are routinely provided while ignoring the propensity of the industry or of those performing the work to complete individual tasks and projects on time. This remains of primary importance as labor costs generally account for at least half of all construction costs, and in many instances may significantly exceed that percentage in labor intensive trades (e.g., electrical).

Compounding this and speaking to its need is the steady decline in construction productivity over the last half century: The US Commerce Department Bureau of Labor Statistics [11] has identified a 40-year average annual productivity decline in the construction industry in excess of ½% per year versus an average increase in productivity of non-construction industries in excess of 1¾%. Simply put, this means that the construction industry as a whole on an ongoing basis spends more and more time each year in labor hour (in hours per dollar of constructed value) to accomplish the same quantity of work, while other industries improve their stance and require less labor each year. Hence, the construction industry seriously lags other industries in developing labor saving ideas or in finding substitutes for labor [12], nor does the industry have an indicative statistic capable of depicting ongoing participant performance.

Therefore, the focus of this research is to examine measures of performance and participant correlation between from other disciplines to determine if they can be extended to the construction industry. That is, this research will examine activities and/or processes based on sound scientific and mathematical principles found in disciplines beyond that of construction and engineering, with the expectation that an analogy by extension, in whole or in part, can be made to portray ongoing schedule performance. The overarching goal of the research is to present by exemplar a method to identify schedule performance of the participants in construction projects governed by network (CPM) schedule systems. This assumes – as is common contracting practice [13] – that an *a priori* baseline schedule (as-planned) exists and is binding for all project participants.

2. CRITERIA FOR ACCESSING PROJECT PERFORMANCE

2.1 Project Performance Indicators Defined

The Project Management Institute (PMI) [14] includes within its body of knowledge an acknowledgement that the integrative nature of project management requires the development and inclusion of monitoring and controlling processes. Jointly, they are essential to successful project management, and are defined as "the process[es] necessary for collecting, measuring, and disseminating performance information, and assessing measurements and trends to effect process improvement" [14, p.61]. When performed continuously, monitoring and controlling provide insight into project health, and include: (1) monitoring ongoing project activities against the project plan and the performance baseline, and (2) influencing the factors that could circumvent change.

The traditional approach to project management performance measurement focuses on the 'iron triangle' of project success criteria [15]; namely cost – the cost to implement the project, quality – the desired quality of the final project outcome, and schedule – the duration required to complete the work. Within the construction arena, these success criteria (or performance indicators) are joined by safety – the level of care and accident freeness experienced during its execution.

Atkinson [15, p.338] further states that "as a discipline project management has not really changed or developed the success measurement criteria for project management in almost 50 years," and that its improvement and metrics are based on past mistakes. Furthermore, the 'iron triangle' does not indicate the level of excellence to which a project was completed or the management sophistication implemented by its team.

2.2 Benchmarking

The criteria by which project success and/or failure are assessed are also called "key performance indicators" or KPIs [15]–[17]. KPIs are a form of benchmarking performance, for which there are multiple characterizations and classification systems. These descriptions include grouping KPIs into categories from which they originate like: (1) the organizational perspective (e.g., resource productivity, organizational learning), (2) the project perspective (e.g., time, customer satisfaction), and 3) the personal perspective (e.g., personal growth and satisfaction) [18].

Benchmarking is focused on establishing a culture of continuous improvement, and has its roots in Total Quality Management (TQM) [19]. It is accomplished by identifying and adopting superior performance practices of other organizations and projects to improve organizational and project-level performance (the development of a schedule performance metric in the context of this research is in-keeping with and a form of benchmarking). Its formal definition as: "A systematic and continuous measurement process; a process of continuously measuring and comparing an organization's business processes against business process leaders anywhere in the world to gain information which will help the organization take action to improve its performance" was established, as Xerox and others pursued consensus in its application as both a measurement and an ongoing comparative process [20].

2.3 Construction Industry Benchmarking

According to the Association for Project Management (APM) and the PMI, project management, including that of the construction industry, embodies multiple competencies that effective project managers should possess [19]. These core competencies – and avenues for benchmarking, as defined by the PMI [1] include; scope, schedule management, cost management, human resources, communication management, risk management, quality, and contract management.

The PMI collection of competencies presents a broad spectrum for developing monitoring and controlling processes; which include all aspects of the expanded 'iron triangle.' Nonetheless, with the exception of the aforementioned cost benchmarking (e.g., R.S. Means, inclusive of productivity rates) the array of published and exchanged KPIs benchmarked by the construction industry is scant.

Beyond the closely-held bonding rates, the most significant exception to this remains the Experience Modification Rate (EMR) established by the National Council on Compensation Insurance with respect to individual company accident/incident history used to establish Workmans' Compensation insurance rates. (The EMR is used well beyond the construction industry, but not with the same significance due to its correlation to the inherent risks of construction activity) While it has been increasingly relied on as a measure of construction safety and performance of individual companies [21], it does not necessarily aptly describe all entities in the construction industry. For example, the EMR of a material supplier may project an artificially successful level of performance when included with other entities with greater propensity for accidents, injuries, or other safety incidents.

In practice, the EMR is a comparison of past losses (occurrences) of the contractor to what is calculated to be the industry "average" losses of other contractors in the same state. It uses audited payroll information and past performance as reported by the subject contractor's insurers compared to the expected losses for an entity in the same line of business, and is adjusted for the size of the company [22]. EMRs typically range between 0.50 and 2.00, where an EMR of 1.0 would indicate that a contractor has an average safety record. EMRs of 0.50 and 2.00 connote performance twice as good (better) and twice as bad (worse) respectively as the calculated expected average. It is considered a benchmark KPI as it is a measure and a controlling process that is calculated over a three-year period.exclusive of the immediate past year.

3. BETA AS A MEASURE OF CORRELATION IN CONSTRUCTION PROJECTS

An analysis of the interaction of participants in a project governed by a CPM schedule is an examination of the internal risks residing therein. Where risk resides, the interrelation of participants (subcontractors) to one another becomes paramount for the way in which risk is measured. Inherent risk becomes recognizable and quantifiable within the project schedule when float (the flexibility to absorb delay) is consumed.

Examination of proven benchmarks in other disciplines landed on the Capital Asset Pricing Model (CAPM) of financial portfolio theory as an appropriate concept for extension to construction projects. It describes the relationship between risk and the expected return of individual stocks to that of the overall market, and is posited to be analogous to the quantification of the inherent risk of the participants in construction projects. The relationship between project participants (schedule activity owners/subcontractors) and their impact on overall schedule performance, defined as schedule risk – the likelihood of failing to meet schedule plans and the effect of such failure, parallels that of the CAPM beta component.

3.1 The Capital Asset Pricing Model

The Capital Asset Pricing Model was introduced independently by Jack Treynor [23], William Sharpe [24], John Lintner [25], and Jan Mossin [26], building on the earlier work of Harry Markowitz [27] on diversification and modern portfolio theory. Sharpe, Markowitz, and Merton Miller (who built upon the theoretical work of Markowitz and Sharpe) shared the 1990 Alfred Nobel Memorial Prize in financial economics [28]. It has been characterized as "one of the most important advances in financial economics" [29, p.295].

Within finance, the CAPM is used to determine a theoretically appropriate required rate of return of an asset, typically a stock, when the stock is to be added to an already well-diversified portfolio (a portfolio of stocks approximating the overall market risk). In its simplest form, the premise of the CAPM is that market participants need to be compensated in two ways: (1) for the time value of money, and (2) for taking on added risk.

The CAPM establishes a linear relationship between a stock portfolio's expected risk premium and the expected market risk premium. The CAPM formula depicted by Eq. 1 and developed by Black, Jensen, and Scholes [30], describes and quantifies this relationship and the expected return for an individual stock, is based upon the assumption that the expected return on the market is equal to the risk-free rate plus some compensation (a premium) for the inherent market risk.

$$E(R_i) = r_f + \beta_i[E(R_m) - r_f] \quad \text{where,} \qquad \text{[Eq. 1]}$$

$E(R_i)$ is the expected return on an individual stock
$E(R_m)$ is the expected return of the overall market
$E(R_m) - r_f$ is known as the 'market premium' or the 'risk premium,' the difference between the expected market rate of return and the risk-free rate of return
r_f is the risk-free rate of interest such as interest arising from government bonds
R_i is the return of an individual asset
R_m is the return of the overall market
β_i, is the sensitivity of the expected excess asset returns to the expected excess market returns

3.2 Beta

Beta, as represented by Eq. 2, is the relevant element to extend to construction project schedule performance. In portfolio theory is has several meanings. First, beta is a number describing the relation of the returns of an asset (an individual stock) or that of a portfolio to those of the entire financial market [31]. It is the seminal element of the CAPM. A beta of 0.50 means that the stock will move at 50% to that of the market (in the same direction).

Beta is also the measure of the volatility, or systematic risk (NB: herein considered akin to schedule risk), of an asset or portfolio in comparison to the risks within the market as a whole. Second, beta is characterized as a measure of financial elasticity (the economic concept that measures the effect of changing one variable to the remaining others), of relative volatility (the measure of price variation over time), of diversifiable and systematic risk, and ultimately of an assets liquidity.

$$\beta_i = \mathrm{Cov}(R_i,R_m) \,/\, \mathrm{Var}\,(R_m) \qquad \text{[Eq. 2]}$$

3.3 Correlation to Construction Project Schedule Performance

Considering that beta is characterized as "the influence [of] the overall market's return on [that of] an individual stock" [32, p. 176], it can be more simply (and appropriately for consideration herein) defined as the asset-specific historic coefficient representing the degree to which an individual stock moves with the market.

Its extension to construction schedule performance is based upon construction projects being formed by disparate entities (subcontractors) who participate in a complex decision-making process that is subject to constraints and uncertainties (schedule risk) as to whether a project will be completed on time. Where individual assets (stocks) form the financial market, the many activities and subcontractors form a project. Building upon financial portfolio theory, the beta component of the CAPM becomes an analogous determinant for the behavior of those participating in construction projects and a potential element in the measure of a risk within network schedule uncertainties and their impacts.

3.4 Schedule Performance Beta

While market interaction and the risk associated with performance can be measured by beta, no such measure exists with network schedule systems. Both financial markets and projects are uncertain and risky decision-making processes. Whereas individual assets have a quantifiable influence on the market via their price fluctuations, so do subcontractors have a yet undetermined level of influence on whether the project will be on schedule (and within budget, though budget performance is not considered herein). This is the very definition of schedule risk – the potential and/or exposure to a loss or other consequences from a project or program not meeting its schedule

Building upon this supposition, "schedule performance" beta can be constructed as represented by Eq. 3 and expressly written for comprehension in Eq. 4. The analogous components forming the schedule performance beta for an individual subcontractor *i*, herein designated as β_{ci}, are presented in Table 1.

$$\beta_{ci} = \mathrm{Cov}(P_{sc},P_p) \,/\, \mathrm{Var}(P_{sc}) \qquad \text{[Eq. 3]}$$

which can be explicitly written as:

$$\beta_{ci} = \frac{\Sigma\left(P_{sc}-\overline{P_{sc}}\right)\left(P_p-\overline{P_p}\right)}{\Sigma\left(P_p-\overline{P_p}\right)^2} \quad \text{where,} \qquad \text{[Eq. 4]}$$

P_{sc} is the subcontractor actual duration

$\overline{P_{sc}}$ is the subcontractor as-planned duration (the performance benchmark)

P_p is the project actual duration

$\overline{P_p}$ is the project as-planned duration (the performance benchmark)

4. SCHEDULE PERFORMANCE MEASURE

The interactions of participants within construction projects, the subcontractors performing the activities necessary to fulfill schedule expectations, parallel in in concept that of the financial market. To translate financial portfolio theory to construction projects

Table 1: Schedule Performance Beta Inputs vs. CAPM Beta Elements

CAPM Beta Input	Variable	Descriptions		Variable	Schedule Beta Input
Asset Rate of Return	R_i	Current Period Asset Value	Subcontractor Actual Duration	P_{sc}	**Schedule Activity Performance**
Asset Return Benchmark	$\overline{R_i}$	Previous Period Asset Value	Subcontractor As-Planned Duration	$\overline{P_{sc}}$	**Schedule Performance Benchmark**
Market Rate of Return	R_m	Current Period Market Value	Project Actual Durations	P_p	**Project Performance**
Market Return Benchmark	$\overline{R_m}$	Previous Period Market Value	Project As-Planned Durations	$\overline{P_p}$	**Project Performance Benchmark**
Financial Beta Significance	β_i	Relationship of Asset Returns to that of the Market Returns	Relationship of Subcontractor Performance to that of the Project Cohort	β_{ci}	**Schedule Performance Beta Significance**

governed by CPM schedule systems and determine a method for defining the specific risk presented by their interaction, this research presents the concept, calculations, analysis, and conclusions by way of an exemplar.

4.1 Exemplar Development

Consider the array of hypothetical schedule results depicted in Table 2. It represents a cohort of 25 completed projects in which three subcontractors participate in at least 20. They have an average as-planned duration of one year (364.4 days), and an actual average duration of 389.8 days. Drawing from the building and transportation project completion studies of Acharya et al. [33] and Bhargava et al. [34] respectively, project actual completion (P_P) fit these results, with 16% finishing ahead of time, 12% as-planned, and 72% finished late.

Actual completion for three subcontractors depicts the performance expected for the variety of sizes, durations, timing, and schedule pressures subcontractors face. Subcontractor ‘A’ is envisioned as a short duration sub with work occurring early in the project – similar to that of an earthwork contractor (one that does not significantly rely on other activities, is duration sensitive and time pressure abounds due to the equipment-intensive nature of the work, and lacks sensitivity to material constraints), subcontractor ‘B’ is envisioned as a long duration sub with work occurring across the majority of the project – similar to that of an electrical contractor one that relies on predecessor work of others before commencing its own, is coordination, material and labor intensive, and has the potential to impact the work of parallel and successor activities), and subcontractor ‘C’ is envisioned as a medium duration sub with work occurring at the end of the project with significant schedule pressure – similar to

Table 2: Exemplar Data and Calculations

Project			**Subcontractor 'A'**			**Subcontractor 'B'**			**Subcontractor 'C'**		
A-P	**ACT**	**Delta**	**A-P**	**ACT**	**Delta**	**A-P**	**ACT**	**Delta**	**A-P**	**ACT**	**Delta**
180	210	30	30	32	2				40	55	15
260	250	-10	45	40	-5	180	195	15	100	75	-25
365	365	0	60	75	15	270	280	10	120	100	-20
210	260	50	25	40	15	150	180	30			
720	695	-25				360	360	0	120	110	-10
360	360	0	20	20	0	210	230	20	90	90	0
130	150	20	10	15	5				5	5	0
180	260	80	30	36	6	100	130	30			
365	395	30	45	60	15	210	220	10	110	105	-5
420	465	45	60	55	-5	320	320	0	90	120	30
630	600	-30				420	400	-20	180	150	-30
270	280	10	40	40	0	195	210	15	120	125	5
410	465	55	75	60	-15	220	260	40	100	75	-25
320	360	40	90	100	10				150	120	-30
120	160	40	10	15	5				30	15	-15
495	460	-35	30	35	5	300	275	-25	120	120	0
230	245	15	45	40	-5	120	90	-30	75	60	-15
390	420	30	90	95	5	300	320	20	90	60	-30
275	350	75	60	75	15	180	180	0	120	95	-25
120	200	80	15	30	15				60	50	-10
560	560	0				460	420	-40	180	175	-5
520	550	30	60	55	-5	400	395	-5	130	115	-15
450	480	30	75	70	-5	320	300	-20	200	150	-50
650	720	70				520	510	-10			
480	485	5	85	75	-10	280	285	5	160	140	-20
	Variance ‘A’	**872.2**		**Covariance ‘A’**	**69.28**		**Covariance ‘B’**	**282.18**		**Covariance ‘B’**	**-17.66**
	Variance ‘B’	**1170.7**		**Beta ‘A’**	**0.079**		**Beta ‘B’**	**0.241**		**Beta ‘C’**	**-0.018**
	Variance ‘C’	**941.63**									

Note: A-P = As-Planned Duration, ACT = Actual Duration, and Delta = Deviation from As-Planned that of a finish subcontractor or that of a systems furniture installer (one that is highly repetitive, commences with the expectation that most all other work has been completed, expects to work with little interference, and has the potential to perform work with increased resources than planned and/or commence portions earlier than expected, thereby presenting the opportunity to accelerate the schedule to 'make up' for previous delays).

4.2 Exemplar Analysis

Beta with respect to schedule performance, β_{ci}, is a measure of the magnitude and direction of a subcontractor's aggregate performance with respect to the performance of an overall project cohort in which they participated. The calculation results for each subcontractor schedule performance beta are shown at the bottom of Table 2, including the variance and covariance elements. The respective betas range from a low on -0.018 to a high of 0.241. They yield in the following analysis.

4.2.1. Subcontractor 'A' $\beta_{cA} = 0.079$: An early activity within the exemplar and of relatively short duration yields a beta of positive value and diminutive magnitude. This characterizes subcontractor 'A' as presenting low specific risk for schedule delays that may impact the work of others, and that of the overall project. This can be attributed to being early work within the schedule (being less likely to experience delays due to the interaction of others and the existence of few predecessors) and that during the early portion the project schedule, the weight of the activity with respect to other project participants remains relatively small.

When putting together a project schedule, inclusion of subcontractor 'A' by a general contractor can be expected to present a schedule risk for extension, for delays beyond the as-planned duration, equal to 0.079 days for every day of overall project delay. Subcontractor 'A' typically represents approximately 8% of the schedule risk experienced within the projects in which it participates.

4.2.2. Subcontractor 'B' $\beta_{cB} = 0.241$: An activity participating in the majority of exemplar project duration yields a beta of positive value and notable magnitude. This characterizes subcontractor 'B' as presenting considerable specific risk for schedule delays that may impact the work of others, and that of the overall project. This can be attributed to participating during the majority of the schedule (being more likely to experience delays due to the interaction of others) and that during the majority of the project schedule, the weight of the activity with respect to other project participants remains high.

When putting together a project schedule, inclusion of subcontractor 'B' by a general contractor can be expected to present a schedule risk for extension, for delays beyond the as-planned duration, equal to 0.241 days for every day of overall project delay. Subcontractor 'B' typically represents approximately 25% of the schedule risk experienced within the projects in which it participates.

4.2.3. Subcontractor 'C' $\beta_{cC} = -0.018$: An late or concluding activity of exemplar project duration with moderate duration yields a beta of negative value and notable magnitude. This characterizes subcontractor 'C' as presenting little to no specific risk for schedule delays that may impact the work of others, and that of the overall project. In fact, the owner of activity subcontractor 'C' routinely performs better than the as-planned schedule duration (hence the negative beat value – it is negatively correlated to overall project performance). This may be attributed to necessity as being one of the last activities to conclude work, with the expectation of 'making up for past delays,' being completed alongside few other activities (being completed independently and less likely to experience delays due to the interaction of others, but most probably experiencing the aggregate delays of predecessor activity).

When putting together a project schedule, inclusion of subcontractor 'C' by a general contractor can be expected to present little schedule risk for extension. It can be expected to reduce its as-planned duration equal to 0.018 days for every day of overall project delay. Subcontractor 'C' typically represents approximately 2% of the schedule acceleration required within the projects in which it participates.

4.3 Implications of Schedule Beta

Schedule performance beta (β_{ci}) for the exemplar project cohort yields results in values within expected range typical of the CAPM beta (β_i). Unlike β_i, schedule performance beta (β_{ci}) is limited by the finiteness of schedule duration. That is, despite experiencing delays, at some point, the project is complete and an upper boundary is formed. Conversely, CAPM beta is theoretically unlimited in that the rate of return of an individual stock may significantly outperform the market by factors of two, three, four, and even more.

More specifically, schedule performance beta is bounded by the upper limit of the overall project duration delta $\left(P_p - \overline{P_p}\right)$, as logic holds that actual duration deviations cannot significantly exceed that of the project to which it belongs. Beyond this, the practical range for β_{ci} fits within a tighter range, conceived heuristically; it is expected that schedule performance beta (β_{ci}) will abide by the following constraints:

Theoretical Range for β_{ci}: $-1.00 < \beta_{ci} < 1.00$

Expected/Practical Range for β_{ci}: $-0.25 < \beta_{ci} < 0.50$

Early activities (subcontractors) with short durations are relegated to the lower end of the beta range, while longer durations and those later in the schedule fill out the higher beta range. Negative betas are expected to be few, and of diminutive value like that of exemplar subcontractor 'C.'

5. CONCLUSIONS

This research began with the supposition that construction managers do not have adequate tools at their disposal to fulfill the PMI expectation for monitoring and controlling their projects. In particular, no schedule performance measures exist to benchmark performance of individual subcontractors against their peers. This led to an examination of performance measures within the construction and engineering profession, as well as looking to those used by other disciplines. The CAPM beta component was recognized as having merit as an analogy to depict the inner workings of project participants (subcontractors) and their ability to complete their work in a timely manner. It can be extended to measure schedule performance in the form of β_{ci}.

This study constitutes *basic research*, because it adapts concepts from seemingly distant areas (financial portfolio theory) and synergistically transfers them to a new application (CPM network schedules), which may unleash novel insights and functional performance measures. Its new theory *is potentially transformative*, because it finally builds a scientific basis for schedule performance measurement to mitigate schedule risk. This can improve performance, reduce disputes, and ultimately realize economic benefits across the construction industry.

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