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DIVISION OF COST DEVIATIONS IN INTEGRATED PROJECT DELIVERY SYSTEMS USING COOPERATIVE GAME THEORY

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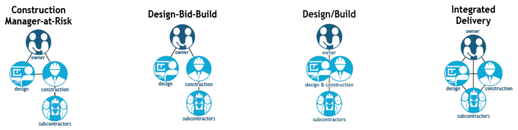
INTRODUCTION

Definition

IPD is defined as a "*project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction*," (AIA CC 2014).



Background

One of the main contractual issues faced in IPD projects under the two contract forms AIA-C191 & ConsensusDocs 300 is the identification, management & allocation of cost deviations using well defined strategies and adequate plans (Ahmed et al. 2021 & Eissa et al. 2024).

An IPD project survival is difficult with an unreasonable distribution mechanism for risk & reward sharing (Guo et al. 2022).

GOAL & OBJECTIVES

Quantifying the IPD objectives based on monetary values **+** Determining cost deviation per project participant **=** Fairly distribute cost deviations in IPD projects between the stakeholders

PROJECT METHODOLOGY

1 Modeling Earned Value Management

EVM is a "*methodology that combines scope, schedule, and resource measurements to assess project performance and progress and forecast project outcome*," (PMI 2019).

2 Dividing the Total Target Band

TTB is a certain sum of money determined at the beginning of the project to represent cost overruns and/or savings up to a certain limit.

3 Determining the Shared Value

SV is the sum of money that will be impartially shared among the core group members.

4 Distributing Shared Value by Cooperative Game Theory

Game theory is *"the study of mathematical modeling of strategic behavior of decision makers (players), in situations where one player's decisions may affect the other players,"* (Parrachino, I. et al. 2006).

MODEL DEVELOPMENT

1

$$CV_i^t = EV_i^t - AC_i^t$$

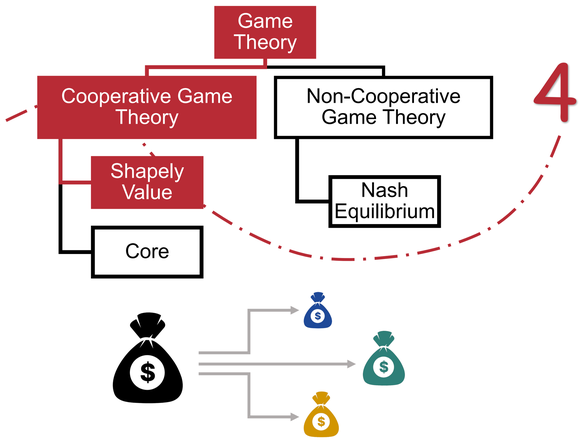
$$TCV^t = \sum_{i=2\ to\ n} CV_i^t$$

2

$$TB^t = \frac{\sum_{i=2\ to\ n} EV_i^t}{TC} \times TTB$$

3

$$SV^t = \begin{cases} 0, & if \quad -\frac{TB^t}{2} \le TCV^t \le \frac{TB^t}{2} \\ TCV^t - \frac{TB^t}{2}, & if \quad TCV^t > \frac{TB^t}{2} \\ \left|-\frac{TB^t}{2}\right| - |TCV^t|, & if \quad TCV^t < -\frac{TB^t}{2} \end{cases}$$



4

Weighted Average — Player i marginal contribution

$$\varphi_i^t = \sum_{S \subseteq n_{i \in S}} \frac{(|S|-1)! * (|n|-|S|)!}{|n|!} * [v(S) - v(S - \{i\})]$$

Marginal Contribution Example

AC: Actual Cost
CV: Cost Variance
EV: Earned Value
i: Player
n: No. of players
v: Worth

S: No. of Players in a coalition
SV: Shared Value
t: milestone
TB: Target Band
TC: Target Cost

TCV: Total Cost Variance
TTB: Total Target Band
φ: Shapely Value

CASE STUDY

IPD Project Information

- *Project Name:* Barrie-Simcoe Emergency Services Campus (BSESC) (Staub-French et al. 2022)
- *Budget:* $85,799,954
- *Duration:* 38 months
- *Core Group Members:* Owner, Architect, & Contractor

Assumptions

- *Total Target Band (TTB):* $8,579,995
- *Target Cost (TC):* $72,929,962
- *Actual Cost (AC):* $76,000,313
- *Project Milestones (T):* 6
- *Contractor Scope:* 90% of *TC*
- *Architect's Scope*: 10% of *TC*

	Months 1-6	Months 7 to 12	Months 13-18	Months 19-24	Months 25-30	Months 31-38
Earned Value	$3.97	$4.58	$19.49	$19.69	$21.57	$3.62
Actual Cost	$3.63	$4.35	$20.53	$20.80	$22.85	$3.85
EV + TB/2	$4.21	$4.85	$20.63	$20.85	$22.84	$3.62
EV - TB/2	$3.74	$4.31	$18.34	$18.53	$20.30	$3.41

Note: All numbers are in Millions

Value Description	Work Value at t for t = 1 to 6					
	Months 1-6	Months 7 to 12	Months 13-18	Months 19-24	Months 25-30	Months 31-38
Architect's CV_2^t	$0.0944	$0.263	$0.0197	$0.0197	$0.0197	$0.007
Contractor's CV_3^t	$0.0164	-$0.028	-$1.065	-$1.293	-$1.293	-$0.228
TCV	$0.345	$0.235	$1.046	-$1.109	-$1.273	-$0.221
TB_t	$0.468	$0.539	$2.293	$2.317	$2.538	$0.426
SV_t	**$0.111**	$0.000	$0.000	$0.000	**-$0.004**	**-$0.008**

Note: All numbers are in Millions

Value Description	Value at t for t = 1 to 6					
	Months 1-6	Months 7 to 12	Months 13-18	Months 19-24	Months 25-30	Months 31-38
$v(1), v(2), v(3)$	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
$v(12)$	$0.094	$0.000	$0.000	$0.000	$0.000	$0.000
$v(13)$	$0.000	$0.000	$0.000	$0.000	-$0.0239	-$0.0148
$v(23)$	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
$v(123)$	**$0.111**	$0.000	$0.000	$0.000	**-$0.004**	**-$0.0083**
Owner's Shapley φ_1	**$0.0527**	$0.000	$0.000	$0.000	**-$0.0054**	**-$0.0053**
Architect's Shapley φ_2	**$0.0527**	$0.000	$0.000	$0.000	**$0.0066**	**$0.0022**
Contractor's Shapley φ_3	**$0.0055**	$0.000	$0.000	$0.000	**-$0.0054**	**-$0.0053**

Note: All numbers are in Millions

RESULTS & DISCUSSION

- The Owner's shapely value is always equal to that of the member responsible for the overrun/ saving.
- The model accounts for a player's positive contribution and incentivizes them accordingly, even if the overall performance of the project at that milestone is negative.
- The shares of each participant differed based on their contribution to a specific time window of the project.
- Distributing deviations along the project duration would either motivate the group members when incentivized or urge them to proactively avoid further overruns.

INDUSTRY CONTRIBUTION

- Address knowledge gap in ConsensusDocs 300 and AIA-C191.
- Promote collaboration in the booming construction industry.
- Ease IPD adoption worldwide.

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