CI & CRC Joint Conference 2024

Des Moines, IA | March 20-23

Division of Cost Deviations in Integrated Project Delivery Systems Using Cooperative Game Theory

Yomna Emad, Mohamed S. Eid, Hesham A. Bassioni

Arab Academy
For Science, Technology and Maritime Transport

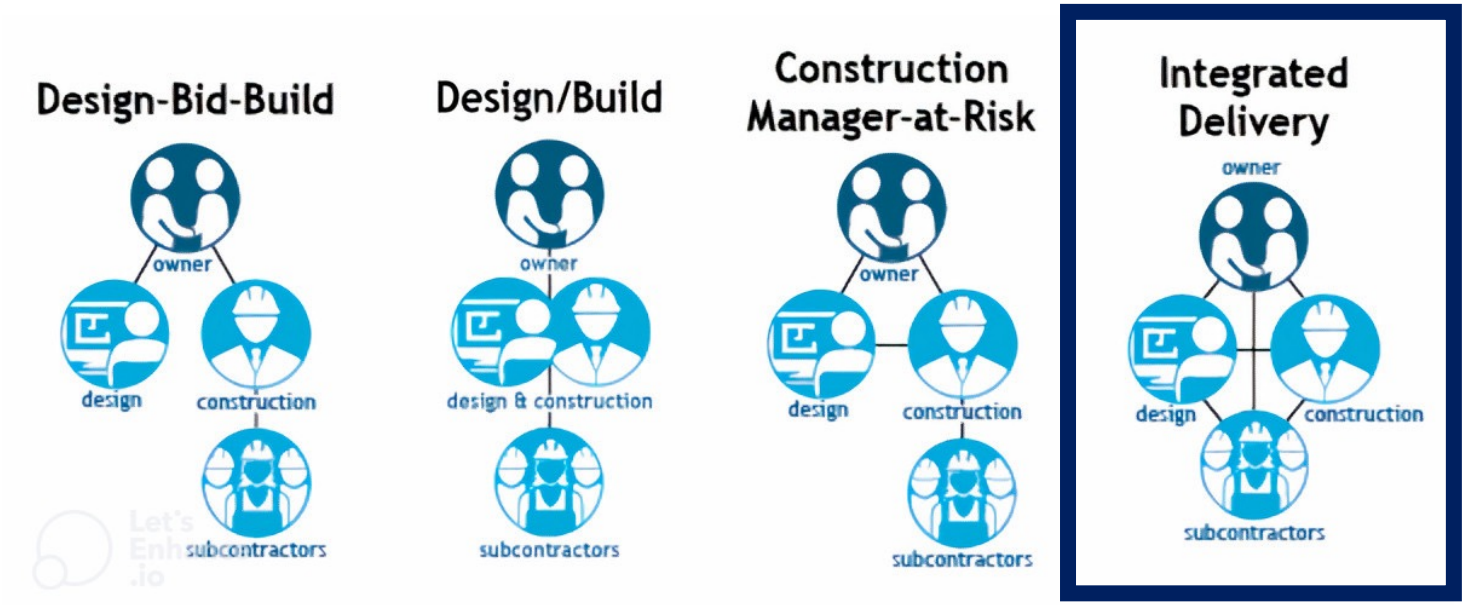
CI ASCE

Iowa State University

Project Delivery Systems

Arab Academy
For Science, Technology and Maritime Transport

A Project Delivery System (*PDS*) "*is the comprehensive process by which a physical entity is designed and constructed* (Gajurel 2014) .



(Webadmin.rexcs, 2021)

Gajurel, A. 2014. *Performance-Based Contracts for Road Projects: Comparative Analysis of Different Types*. New Delhi: Springer India.

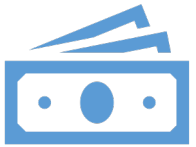
What is IPD?

Arab Academy
For Science, Technology and Maritime Transport

Early involvement of all project participants

One contract agreement between the primary project participants

Information sharing and transparent communications



Shared risks and incentives

Background

Arab Academy
For Science, Technology and Maritime Transport

Ahmed et al. 2021 & Eissa et al. 2024

- Main contractual issues facing IPD projects under AIA-C191 and ConsensusDocs 300: identification, management and allocation of cost deviations, etc.

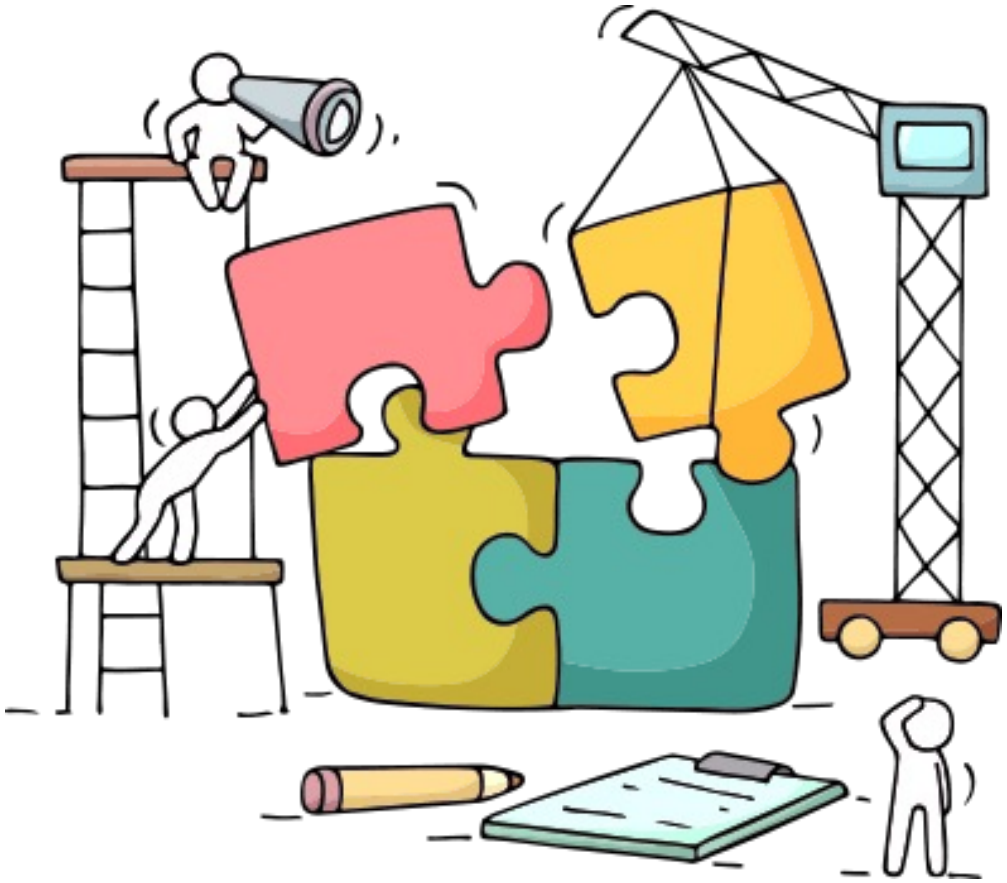
Guo et al. 2022

- Distribution mechanism for risk and reward sharing is essential for IPD survival.

Ahmed, M. O., M. Abdul Nabi, I. H. El-adaway, D. Caranci, J. Eberle, Z. Hawkins, and R. Sparrow. 2021. "Contractual Guidelines for Promoting Integrated Project Delivery." *J. Constr. Eng. Manag.*, 147 (11): 05021008. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002173.
Eissa, R., M. Abdul Nabi, and I. H. El-adaway. 2024. "Risk–Reward Share Allocation under Different Integrated Project Delivery Relational Structures: A Monte-Carlo Simulation and Cooperative Game Theoretic Solutions Approach." *J. Constr. Eng. Manage.*, 150 (4): 04024013. https://doi.org/10.1061/JCEMD4.COENG-13181.
Guo, S., J. Wang, and H. Xiong. 2022. "The influence of effort level on profit distribution strategies in IPD projects." *Eng. Constr. Archit. Manag.* https://doi.org/10.1108/ECAM-02-2022-0107.

Research Gap

The lack of a model that fairly **distributes / divides** cost savings and/or overruns, *(Cost Deviations)*.



Goal & Objectives

Arab Academy
For Science, Technology and Maritime Transport

Quantifying the IPD objectives based on monetary values

+

Determining cost deviation per project participant

=

Fairly distribute cost deviations in IPD projects between the stakeholders

Arab Academy
For Science, Technology and Maritime Transport

Methodology

Modeling Earned Value per Milestone

Dividing the Total Target Band per Milestone

Distributing the Shared Value by adopting the Shapley Value

Determining the Shared Value

Arab Academy
For Science, Technology and Maritime Transport

Model Development

STEP 1

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

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

Created by Flat Icons

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

v: Worth
S: No. of Players in a coalition
S:V Shared Value
***t*:** milestone
TB: Target Band

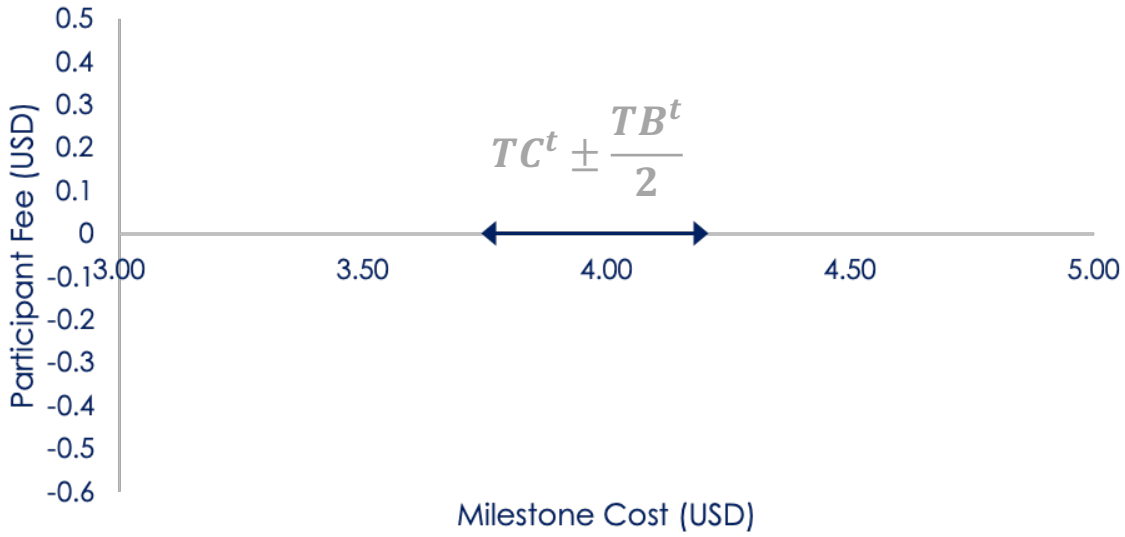
TC: Target Cost
***TCV*:** Total Cost Variance
TTB: Total Target Band
φ: Shapely Value

Arab Academy
For Science, Technology and Maritime Transport

Model Development

STEP 2

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



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

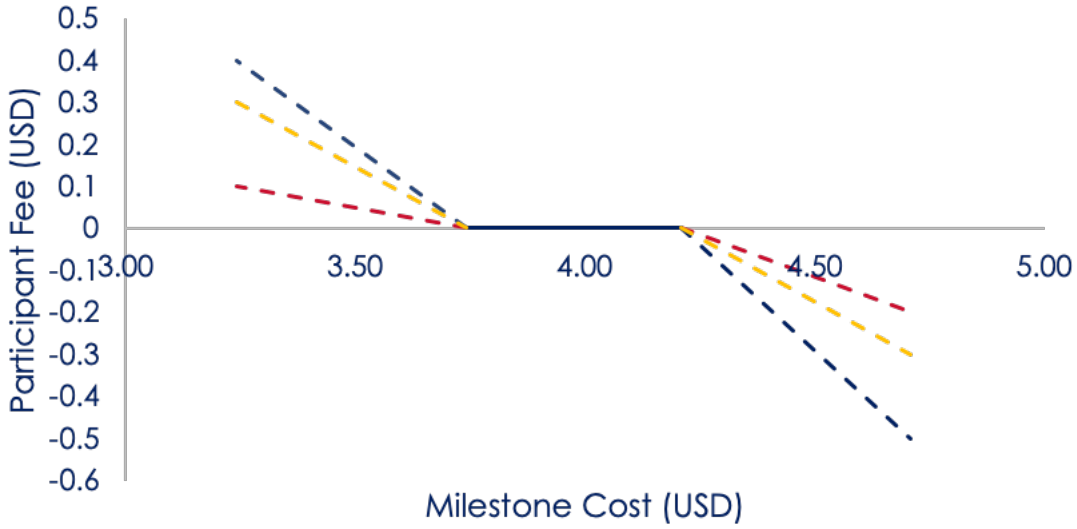
TC: Target Cost
TCV: Total Cost Variance
TTB: Total Target Band
φ: Shapely Value

Arab Academy For Science, Technology and Maritime Transport

Model Development

STEP 3

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



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

Arab Academy
For Science, Technology and Maritime Transport

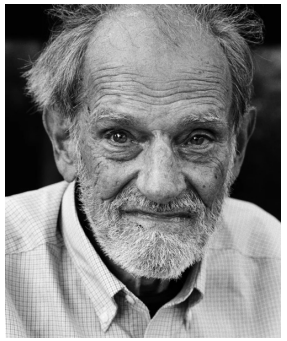
Model Development

STEP 4

Weighted Average

Player i marginal contribution

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



Lloyd Stowell Shapley
1923-2016

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

Staub-French, S., P. Zadeh, D. Bhonde, C. Webber, K. Jaeger, K. Consulting, M. Allison, M. Williams, P. Taylor, J. Ford, L. Consulting, D. Loewen, A. Mechanical, P. Sprokay, Erik A. Poirier, and Ahmad Arar. 2022. *INVESTIGATING FACTORS LEADING TO IPD PROJECT SUCCESS IN CANADA*. 143. UNIVERSITY OF BRITISH COLUMBIA; ECOLE DE TECHNOLOGIE SUPERIEURE; INTEGRATED PROJECT DELIEVERY ALLIANCE.

Case Study

Barrie-Simcoe Emergency Services Campus (BSESC)

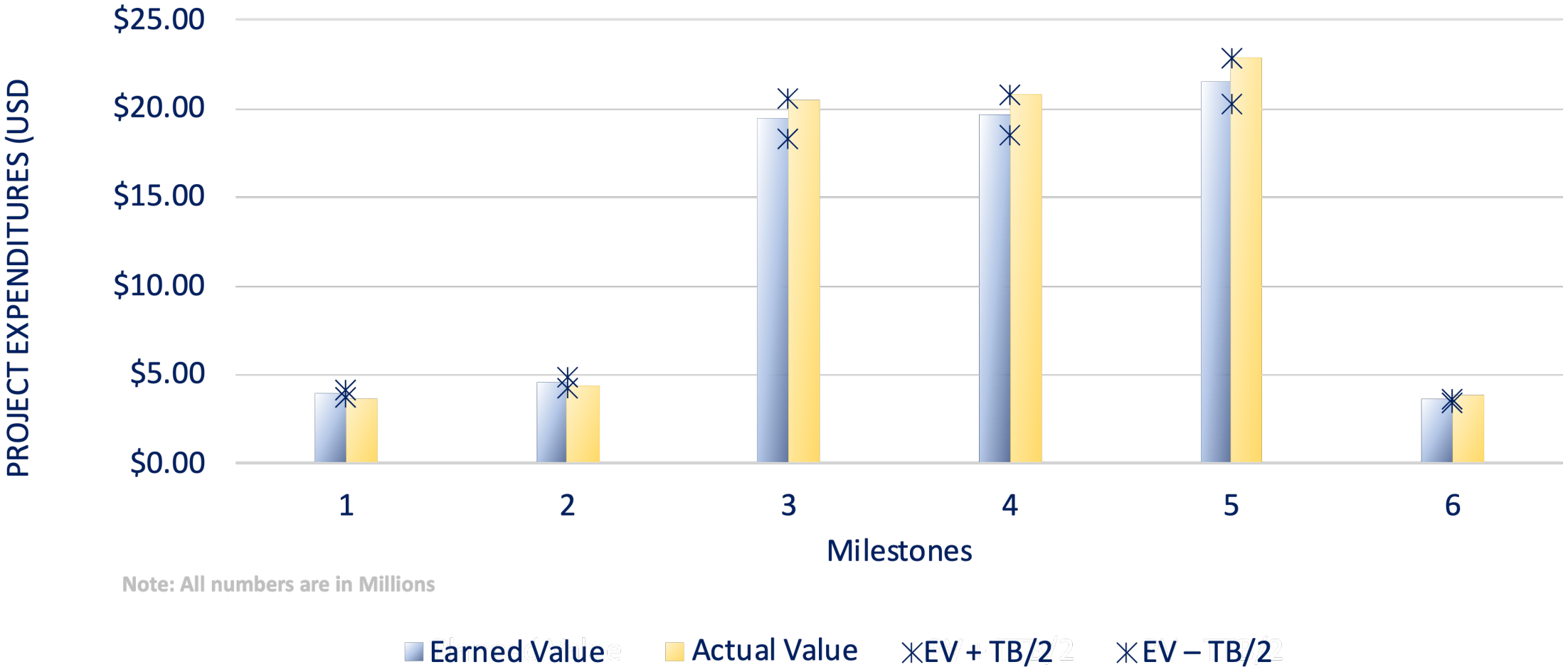
- **Budget:** $85,799,954
- **Duration:** 38 months
- **Delivery System:** IPD
- **Core Group Members:** Owner, Architect, & Contractor
- **Project Location:** Ontario, Canada

Case Study

Barrie-Simcoe Emergency Services Campus (BSESC)

Assumptions

- Total Target Band (TTB): $8,579,995
- Target Cost (TC): $72,929,962
- Actual Cost (AC): $76,000,313
- Project Milestones (T): 6


PROJECT EXPENDITURES (USD
$25.00
$20.00
$15.00
$10.00
$5.00
$0.00
1
2
3
4
5
6
Milestones
Note: All numbers are in Millions
Earned Value
Actual Value
EV + TB/2
EV – TB/2

Arab Academy For Science, Technology and Maritime Transport

Case Study

Value Description	Work Value at t for t= 1 to 6					
	Months 1-6	Months 7-12	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	-$1.129	-$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

Arab Academy
For Science, Technology and Maritime Transport

Case Study

Participant	φ	Shapely Value at t		
		Months 1-6 (t=1)	Months 25-30 (t=5)	Months 31-38 (t=6)
Owner	φ_1	$0.0527	-$0.0054	-$0.0053
Architect	φ_2	$0.0527	$0.0066	$0.0022
Contractor	φ_3	$0.0055	-$0.0054	-$0.0053

Note: All numbers are in Millions

Results & Discussion

Owner's shapely value

Image by Vectorarte on Freepik

Contribution to a specific time window

Image by pch.vector on Freepik

Positive/ negative contribution

Image by vectorjuice on Freepik

Motivation/ Proactive Response

Money illustrations by Storyset

Future Recommendations

Arab Academy
For Science, Technology and Maritime Transport

- Effect of **time**
- Validation of results by a larger number of **case studies**
- Quantify an **Architect's efforts**
- Introducing the framework to **work professionals** in the industry

IOWA STATE UNIVERSITY

Arab Academy
For Science, Technology and Maritime Transport

Thank You!