Optimizing product development projects under asynchronous and aperiodic system-local interactions

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Work Transformation Matrix (WTM)

WTM = quantitative DSM, focused on works

DSM

	A	B	C	D	E
A				x	x
B				x	
C	x			x	
D		x			
E			x	x	

WTM

Within A

	A	B	C	D	E
A	0.6			0.6	0.2
B		0.5		0.1	
C	0.1		0.4	0.7	
D		0.1		0.5	
E			0.1	0.9	0.6

From D to E

Fraction of work amounts that is transferred to / kept within modules

Smith, Eppinger, "Identifying controlling features of engineering design iteration," *Management Science*, 1997.

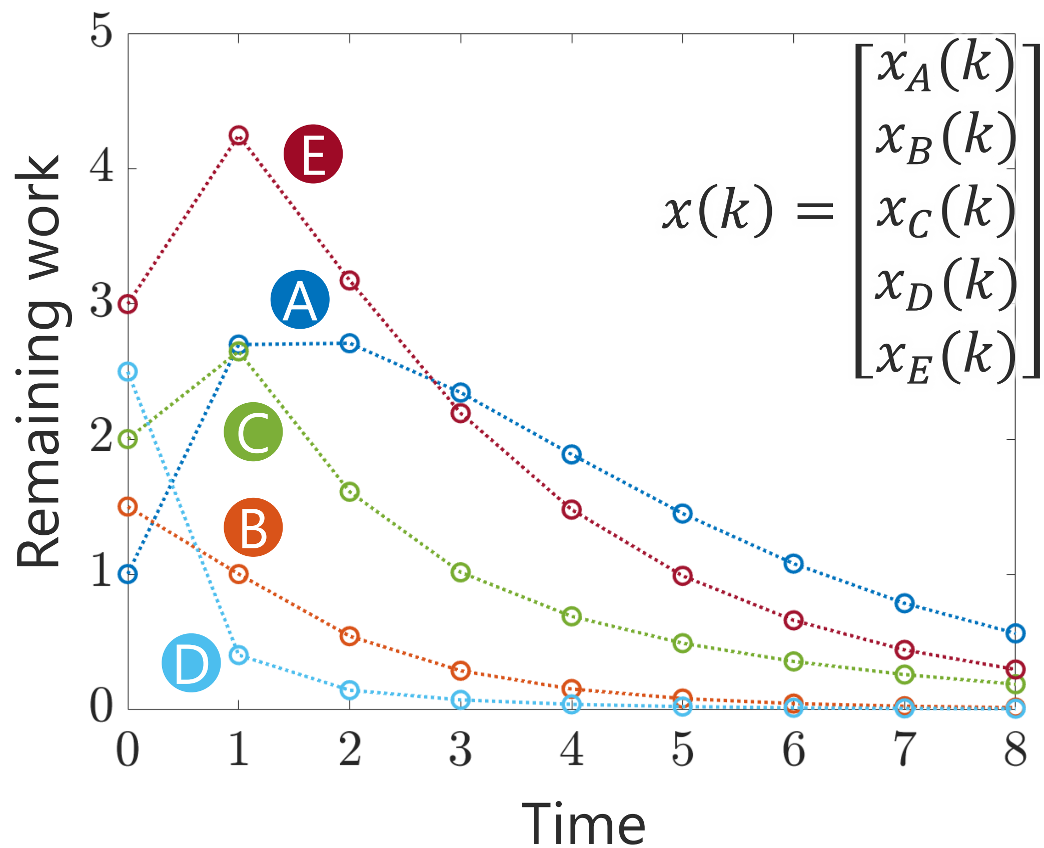
How WTM works

WTM

$$x(k+1) = Wx(k)$$

Vector of remaining work

	A	B	C	D	E
A	0.6			0.6	0.2
B		0.5		0.1	
C	0.1		0.4	0.7	
D		0.1		0.5	
E			0.1	0.9	0.6



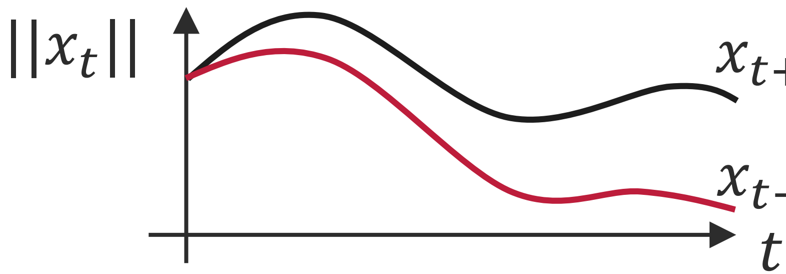
Resource allocation for PD process acceleration

HR management, information technology, resolving dependency, ...

Improvement of WTM

$$W \rightarrow V$$

PD process acceleration



$$x_{t+1} = W x_t$$

$$x_{t+1} = V x_t$$

Optimal improvement within budget?

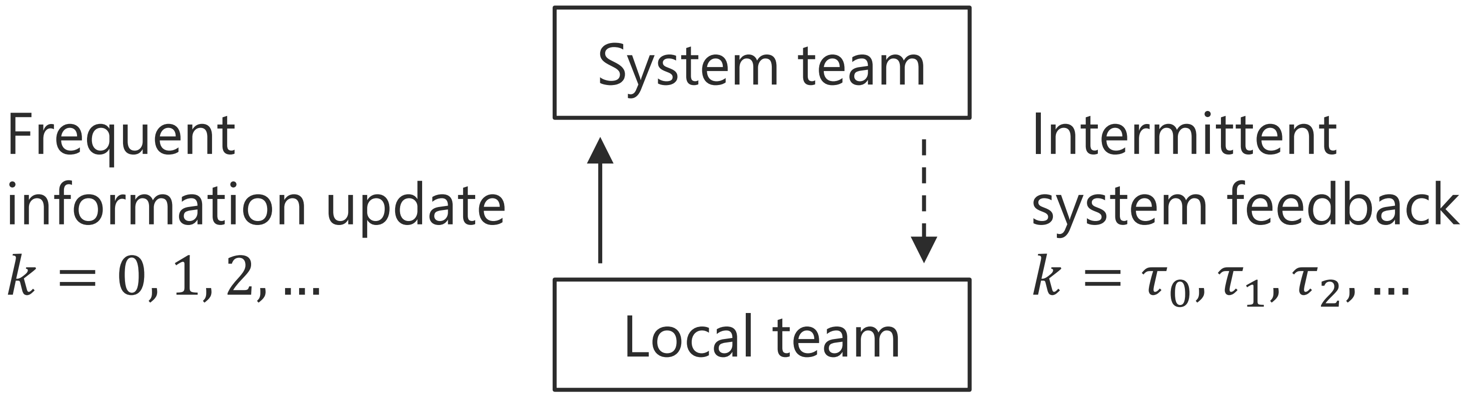
Several options...

$$W = \begin{bmatrix} 1/2 & 1 \\ 1 & 1/2 \end{bmatrix} \rightarrow$$

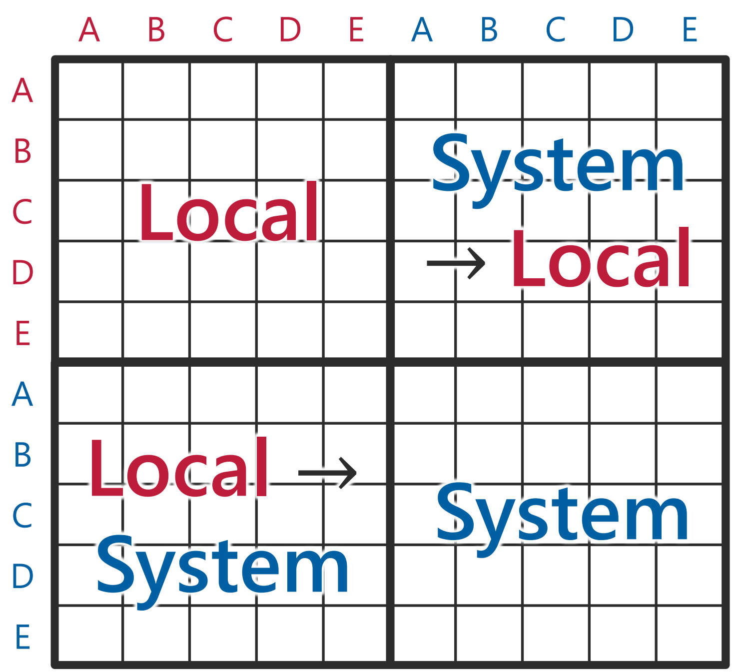
$$V = \begin{bmatrix} \mathbf{0} & 1 \\ 1 & 1/2 \end{bmatrix}$$

$$V = \begin{bmatrix} 1/2 & \mathbf{1/2} \\ 1 & 1/2 \end{bmatrix} \quad V = \begin{bmatrix} \mathbf{1/4} & 1 \\ 1 & \mathbf{1/4} \end{bmatrix}$$

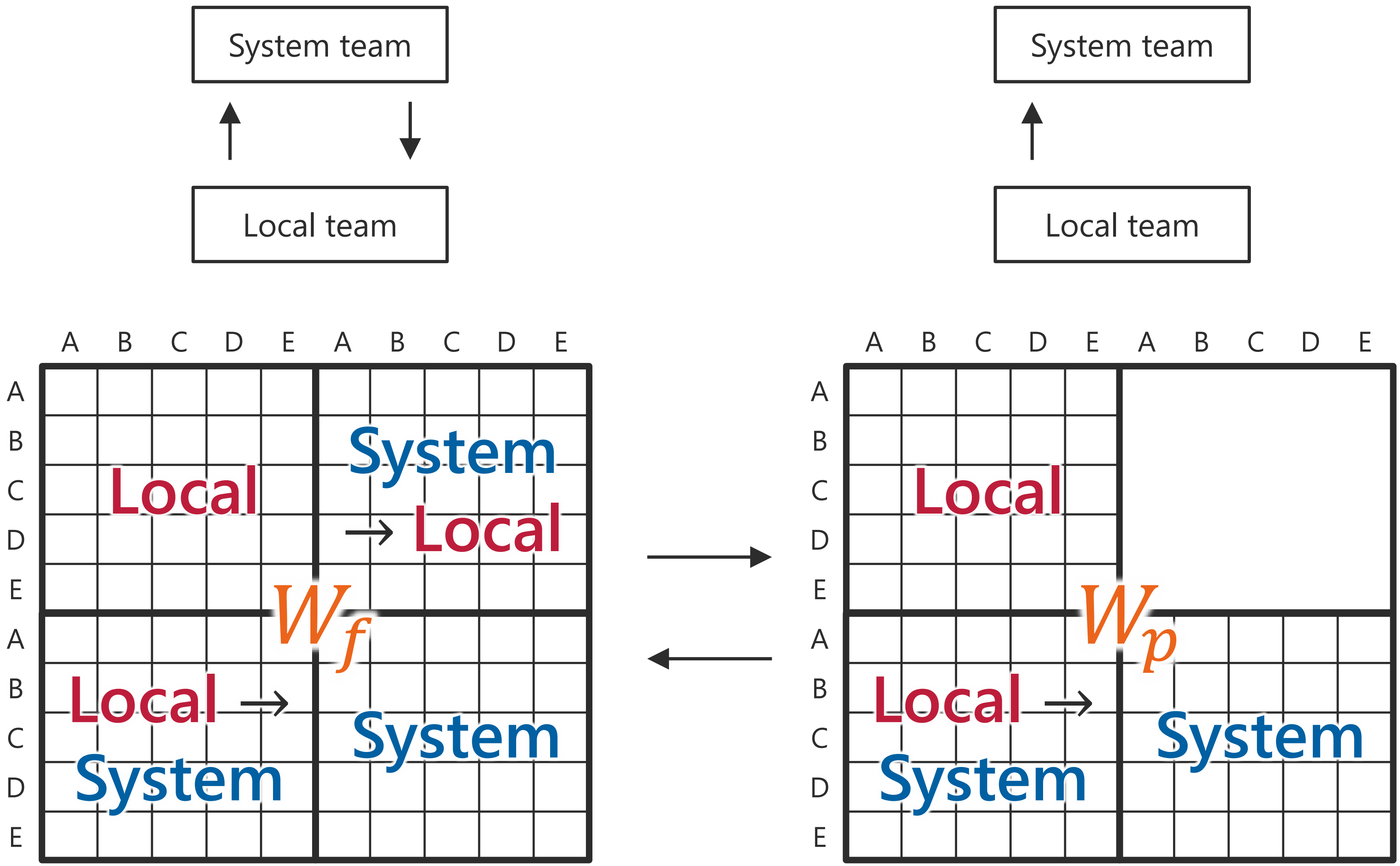
System/local structure [Yassine et al., *RIED*, '03]



Extended WTM structure

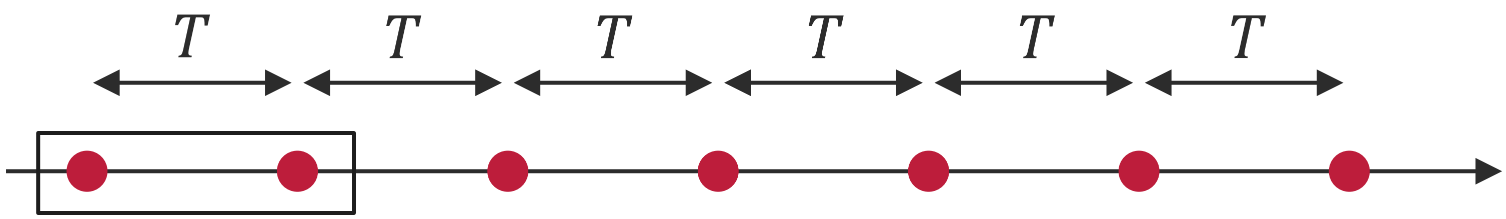


Time-varying WTM



Coping with uncertainty

Periodic system feedback [Yassine et al., *RIED*, 2003]

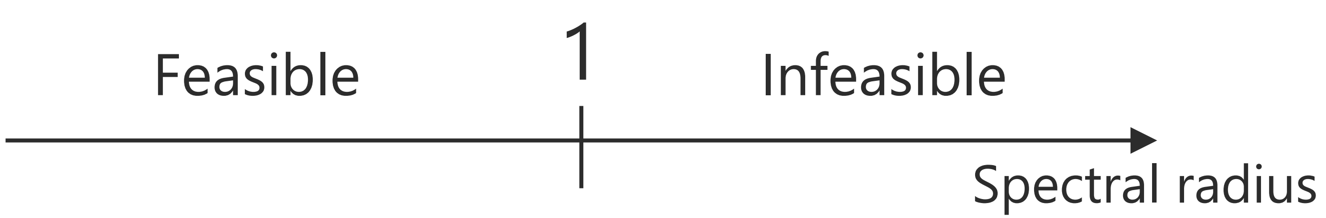


- Transition of remaining work

$$x \;\rightarrow W_p x \rightarrow W_p^2 x \rightarrow \cdots \rightarrow W_p^{T-1} x \rightarrow W_f W_p^{T-1} x$$

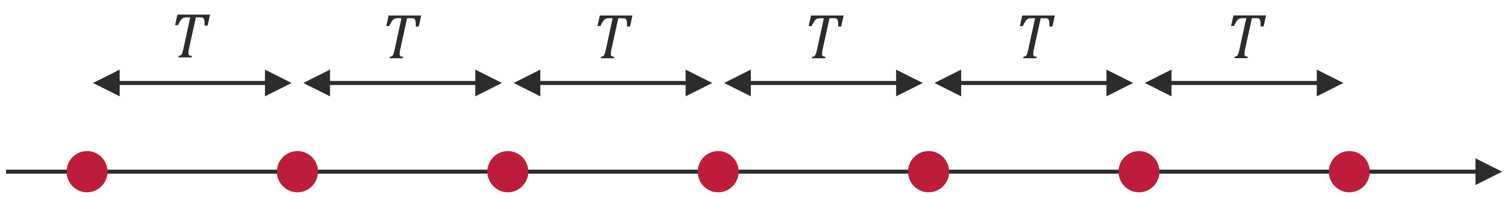
Generalized WTM
Determines feasibility of PD process

- Spectral radius as a feasibility index



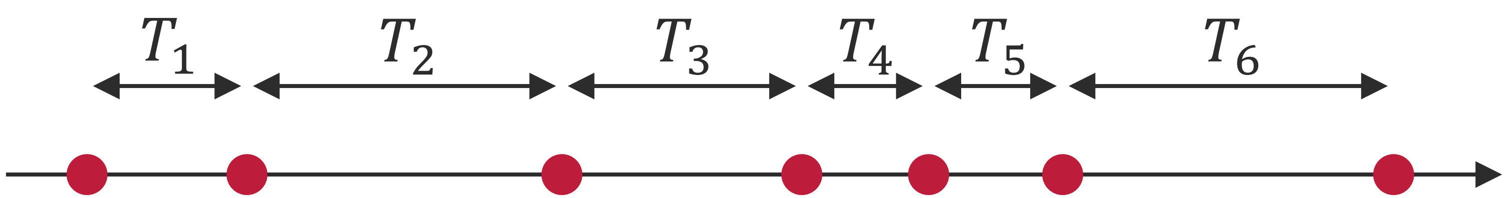
Coping with uncertainty

Periodic system feedback [Yassine et al., *RIED*, 2003]



System feedback may not necessarily occur regularly

Aperiodic system feedback (this research)



Assumption: T_k's are independent and identically distributed random variables

Theoretical results

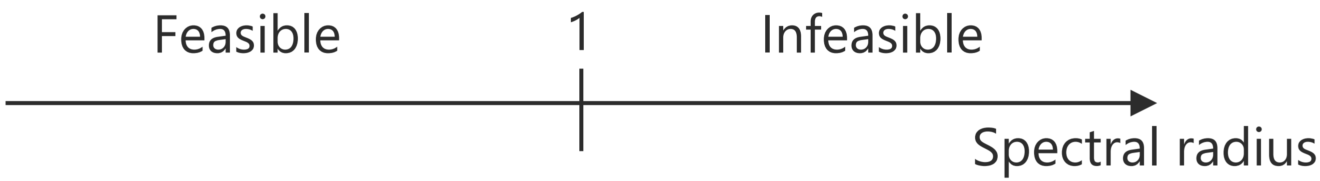
Result 1: Generalized WTM

T = random interval

$$M = E[W_f W_p^{T-1}]$$

mathematical expectation

- Spectral radius as a feasibility index



Process improvement problem

How should we distribute our managerial resource to minimize the feasibility index $\rho(M)$?

Theoretical results

Result 2:

Resource allocation problem can be solved via convex optimization.

- Scales well with respect to the size of PD process
- Very fast solvers available: allows making quick decisions
- Details in the proceeding: geometric programming plays a key role

Automobile appearance design [McDaniel, '96]

Case overview

- Part of automobile PD process
- Process of designing all interior and exterior auto-mobile surfaces for better appearance, surface quality, and operational interface.

- Engineering (local) team responsible for the feasibility of designs
- Styling (system) team responsible for the appearance of the vehicle

- Tasks: (1) carpet, (2) center console, (3) door trim panel, (4) garnish trim, (5) overhead system, (6) instrument panel, (7) luggage trim, (8) package tray, (9) seats, and (10) steering wheel.

Automobile appearance design [McDaniel, '96]

Nominal WTMs

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
S_1	0.2									
S_2		0.2								
S_3			0.2							
S_4				0.2						
S_5					0.2					
S_6						0.2				
S_7							0.2			
S_8								0.2		
S_9									0.2	
S_{10}										0.2

System DSM Ω_S

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
S_1										
S_2			0.09	0.17	0.21	0.09	0.14	0.42	0.29	0.38
S_3		0.12		0.6	0.24	0.1	0.16	0.49	0.34	0.44
S_4		0.06	0.15		0.12		0.16	0.49	0.08	0.22
S_5		0.05		0.08						
S_6		1	0.87	0.58			0.94	1.41	0.49	3.81
S_7		0.07	0.06	0.25						
S_8				0.08					0.07	
S_9		0.14	0.12	0.12				0.58		
S_{10}				0.05						

IDM Ω_{LS} (converting local issues to systems issues)

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
L_1	0.15									
L_2		0.15								
L_3			0.15							
L_4				0.15						
L_5					0.15					
L_6						0.15				
L_7							0.15			
L_8								0.15		
L_9									0.15	
L_{10}										0.15

IDM Ω_{SL} (converting system issues to local issues)

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
L_1	0.85	0.12	0.02	0.06	0.06				0.06	
L_2	0.1	0.53	0.04			0.3	0.02		0.24	0.02
L_3	0.02	0.04	0.47	0.08		0.24	0.02		0.18	0.02
L_4	0.06		0.18	0.68		0.14	0.1	0.02	0.08	
L_5	0.04				0.83					
L_6		0.30	0.26	0.16		0.28	0.06		0.02	0.2
L_7		0.02	0.02	0.1		0.06	0.76	0.06	0.04	
L_8				0.1			0.06	0.83	0.16	
L_9	0.08	0.24	0.18	0.08		0.04	0.04	0.16	0.63	0.2
L_{10}		0.02	0.02			0.26			0.2	0.7

Local DSM Ω_L

Fig. 2 Nominal DSMs and IDMs of the automotive appearance design. The inter-component and inter-team dependencies (18) that can be weakened by the manager are highlighted with the gray color

Problem formulation

Assumption

- Maximum reduction = 15%
- Reduction cost proportional to reduction amount
- Feedback intervals randomly fluctuated
- Question: Which DSM entry should we invest on?

Comparison

- Eigenvector-based method assuming constant feedback intervals [Yassine, *RIED*, 2003]

Results

Comparison of investment pattern

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
L_1		0	0	0	0				0	
L_2	0		0			30.0	0		0	0
L_3	0	0		0		24.0	0		0	0
L_4	0		0			14.0	0	0	0	
L_5	0									
L_6		0	0	0			0		0	0
L_7		0	0	0		0		0	0	
L_8				0			0		0	
L_9	0	8.1	2.1	0		4.0	0	0	0	0
L_{10}		1.6	1.2			26.0			1.9	

(a) $f_{L,ij}(\Psi_{L,ij})$

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
S_1										
S_2			0	0	0	0	0	0	0	0
S_3		0		0	0	0	0	0	0	0
S_4		0	0		0		0	0	0	0
S_5		0		0						
S_6		0	0	0			0	0	0	0
S_7		0	0	0						
S_8				0					0	
S_9		0	0	0				0		
S_{10}				0						

(b) $f_{LS,ij}(\Psi_{LS,ij})$

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
L_1	0									
L_2		7.2								
L_3			15.0							
L_4				0						
L_5					0					
L_6						15.0				
L_7							0			
L_8								0		
L_9									0	
L_{10}										0

(c) $f_{SL,ij}(\Psi_{SL,ij})$

Proposed

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
L_1		2.6	0.4	0	0				0	
L_2	2.1		0.9			6.4	0.4		5.1	0.4
L_3	0.4	0.9		1.7		5.1	0.4		3.9	0.4
L_4	0		3.9			3.0	0	0	0	
L_5	0									
L_6		6.4	5.6	3.4			1.3		0.4	4.3
L_7		0.4	0.4	0		1.3		0	0	
L_8				0			0		0	
L_9	0	5.1	3.9	0		0.9	0	0	0	0
L_{10}		0.4	0.4			5.6			0	

(a) $f_{L,ij}(\Psi_{L,ij})$

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}
S_1										
S_2			1.9	0	0	1.9	0	0	0	0
S_3		2.6		0	0	2.1	0	0	0	0
S_4		1.3	3.2		0		0	0	0	0
S_5		1.1		0						
S_6		21.6	18.6	0			0	0	0	0
S_7		1.5	1.3	0						
S_8				0					0	
S_9		3.0	2.6	0				0		
S_{10}				0						

(b) $f_{LS,ij}(\Psi_{LS,ij})$

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
L_1	0									
L_2		3.2								
L_3			3.2							
L_4				0						
L_5					0					
L_6						3.2				
L_7							0			
L_8								0		
L_9									0	
L_{10}										0

(c) $f_{SL,ij}(\Psi_{SL,ij})$

Conventional

Feasibility index

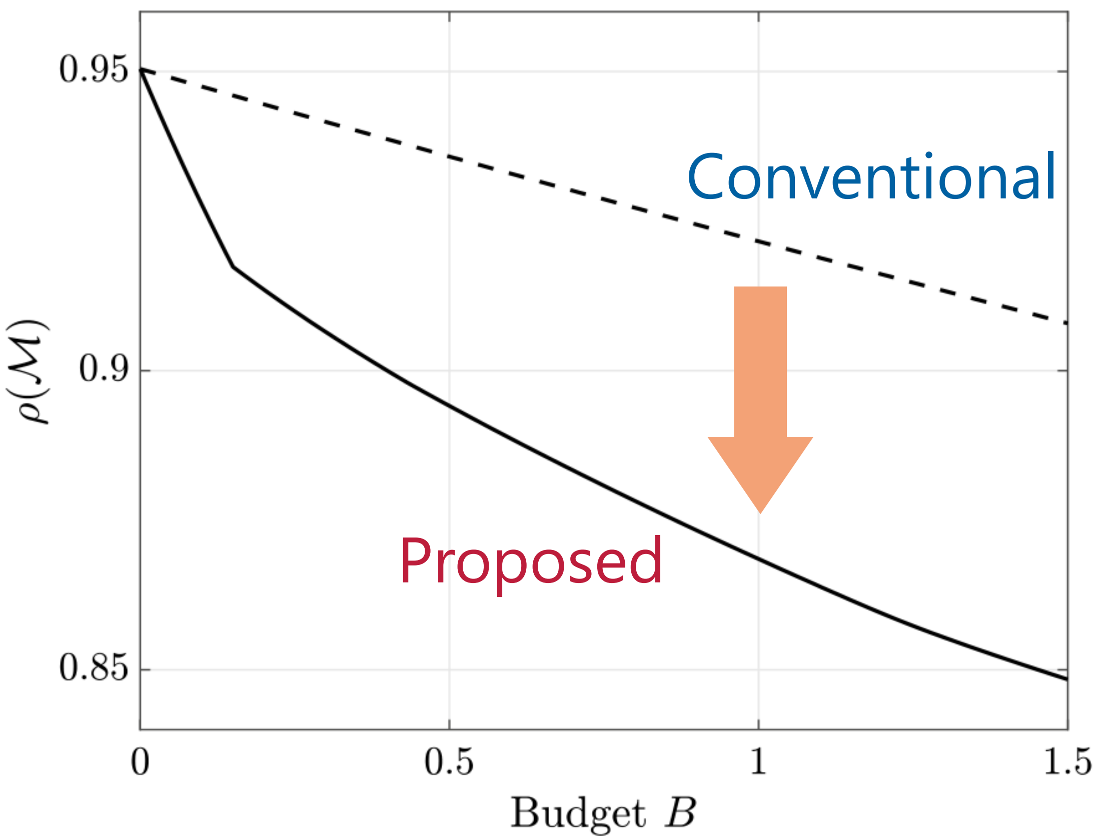
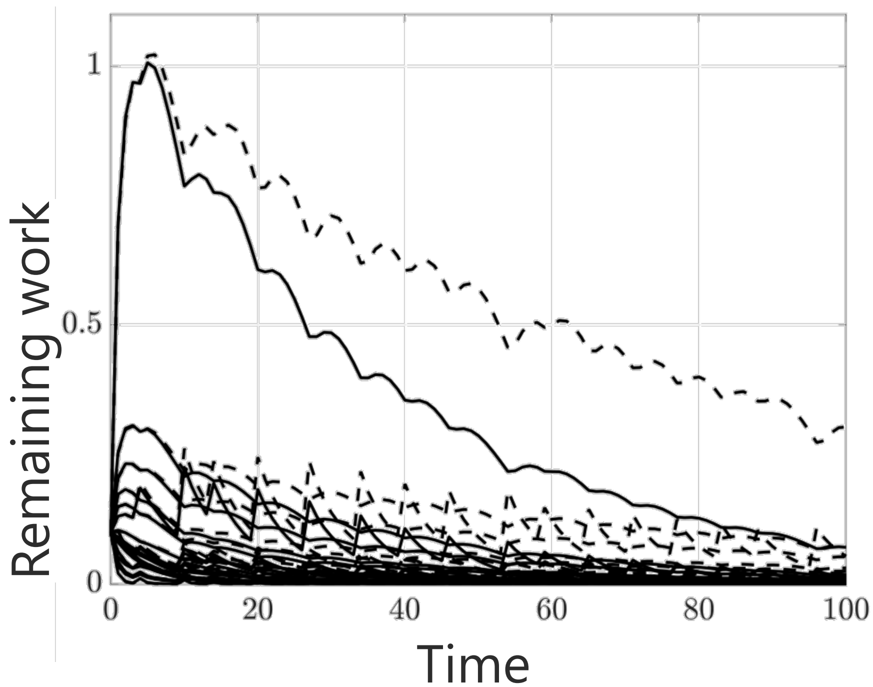
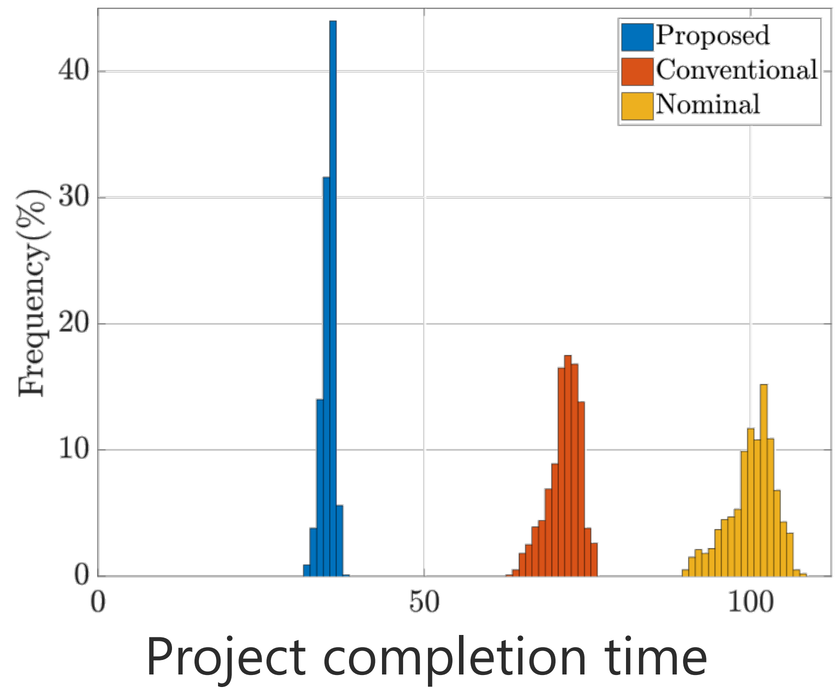


Fig. 7 Performances of the baseline and proposed strategies for various values of the budget B. Solid line: proposed strategy. Dashed line: baseline strategy

PD process simulation





Conclusion

Optimal resource allocation for improving PD processes

- Theoretical analysis: Feasibility index
- Based on tools from systems and control engineering
- Decision support tool based on convex optimization
- Improves existing heuristic methodology based on eigenvector centralities

Thank you!

Journal version: Ogura, Harada, Kishida, Yassine, “Resource optimization of product development projects with time-varying dependency structure,” *Research in Engineering Design*, vol. 30, no. 3, pp. 435–452, 2019.