

System Development in Dynamic Environments: Tools for architecture development and process management

Prof. Yoram Reich
School of Mechanical Engineering
Faculty of Engineering, Tel Aviv University

With collaboration of
Dr. Avner Engel, Dr. Arie Karniel, Yuri Belsky

Outline

- *Unpredictable* dynamic environments
- Product development paradox
- Product architecture
- Robust product concept
- Development processes
- Conclusions

Unpredictable dynamic environments

- Dynamic environments could be unpredictable
 - ◆ Environment changes
 - ◆ Changes could be unpredictable, incomprehensible, due to our **incomplete knowledge of the world**
 - ◆ Changes lead to further environmental changes

More SE → better performance

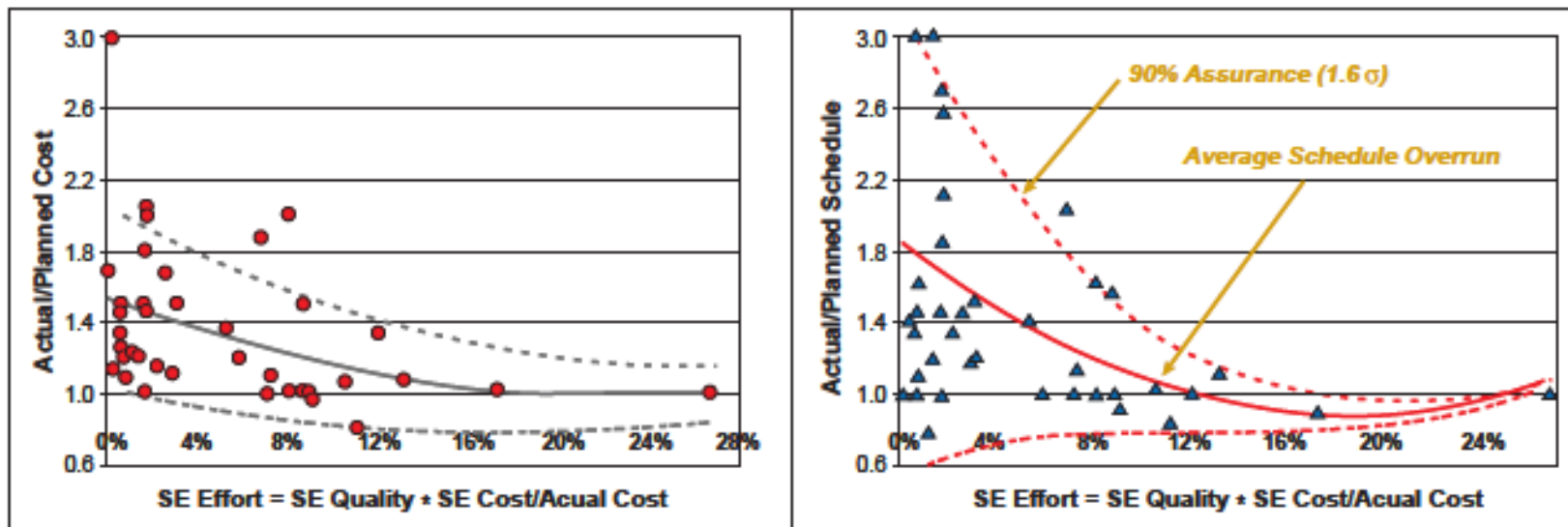
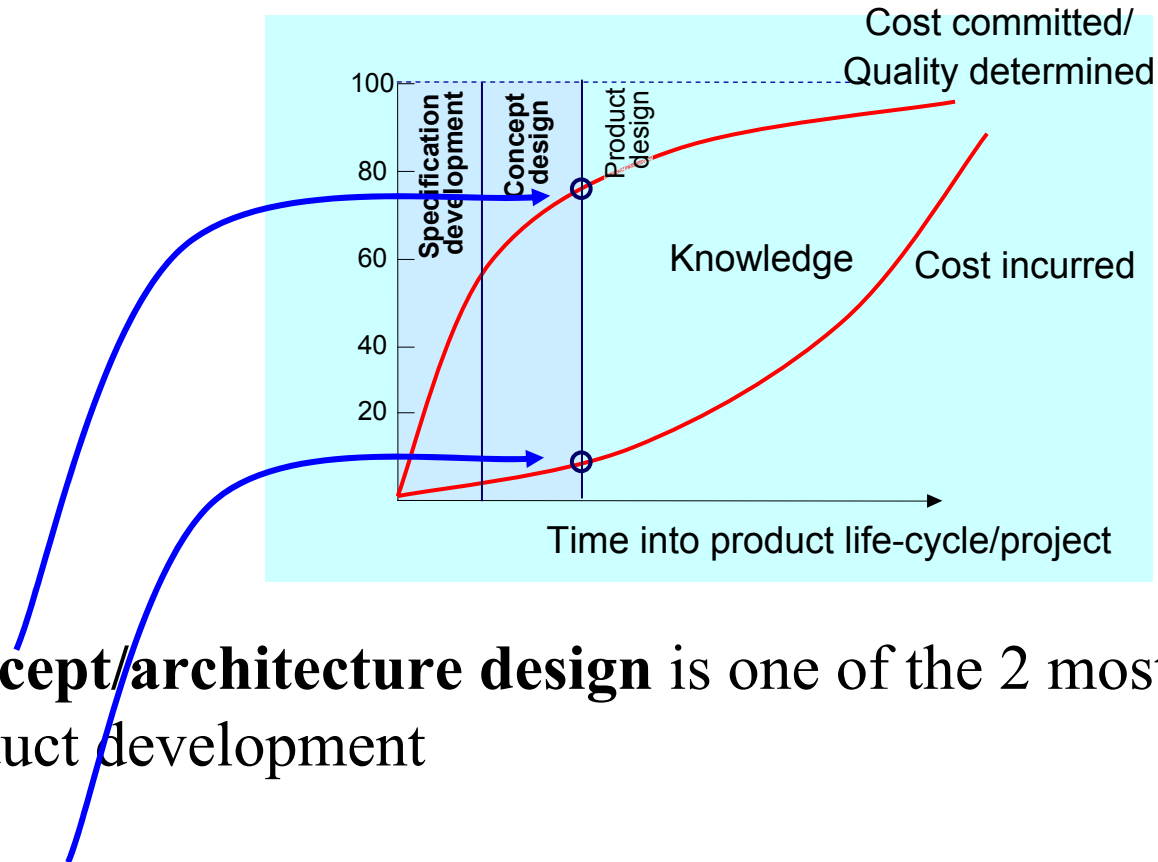


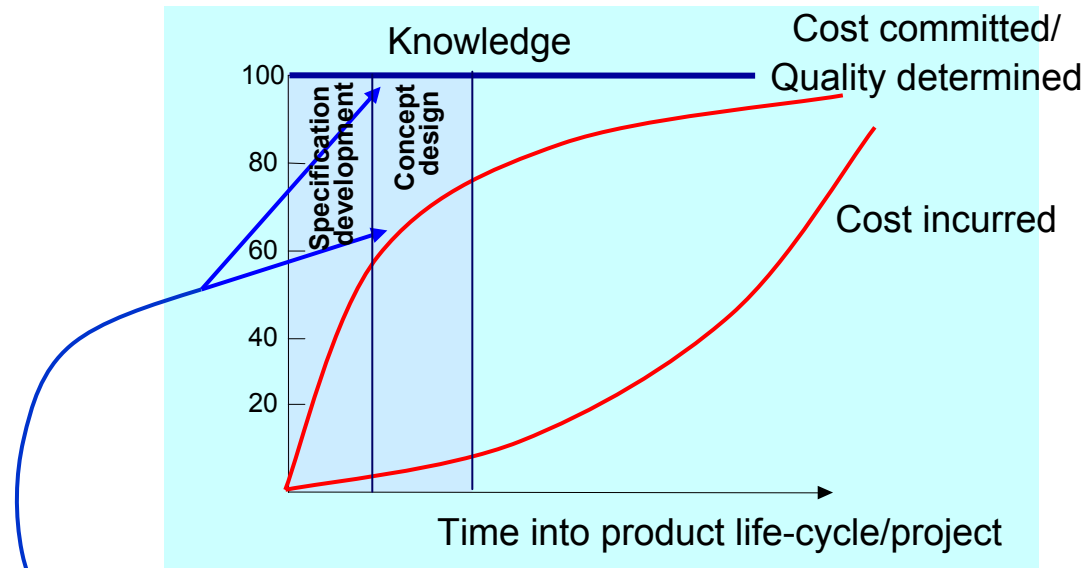
Figure 2-5 Cost and schedule overruns correlated with systems engineering effort¹²

More *upfront* SE → more impact



- **Concept/architecture design** is one of the 2 most critical steps in product development
- Resource spending on this project stage is <5%-10% of budget

The product development **fantasy**

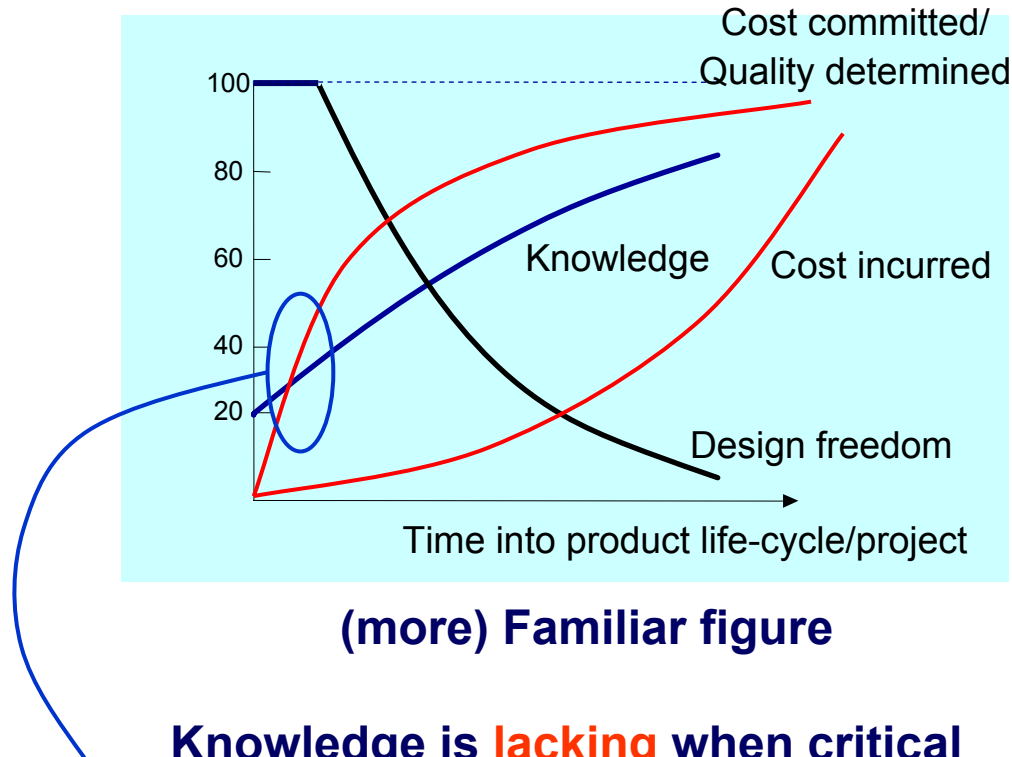


Knowledge is available to make the best choices when decisions are required

... there are no changes in the product, no design iterations

... design can be done in parallel, reducing time-to-market

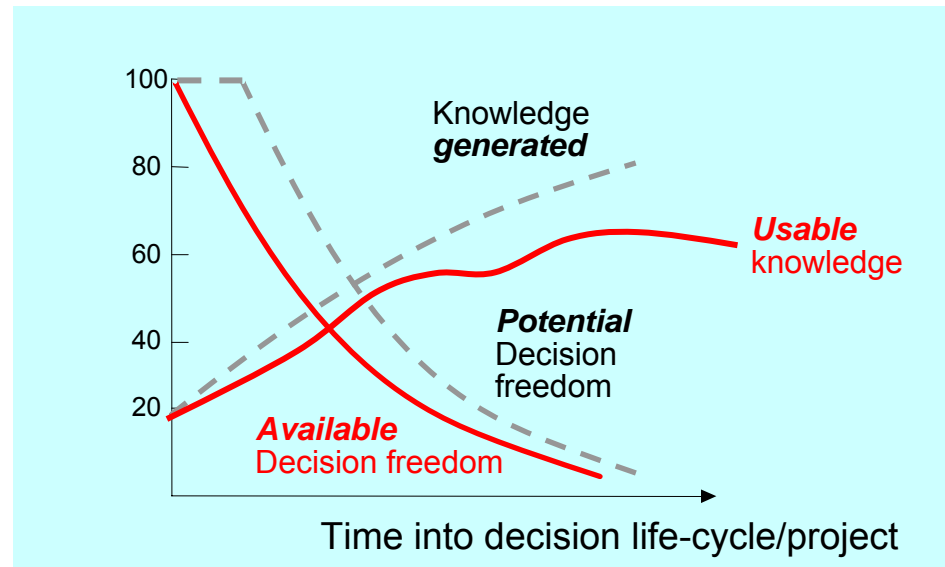
The product development **paradox (PDP)**



Knowledge is **lacking** when critical decisions are made

... by the time we have knowledge, design freedom diminishes, cost have been committed and changes are costly

The product development **paradox** (PDP) (2)

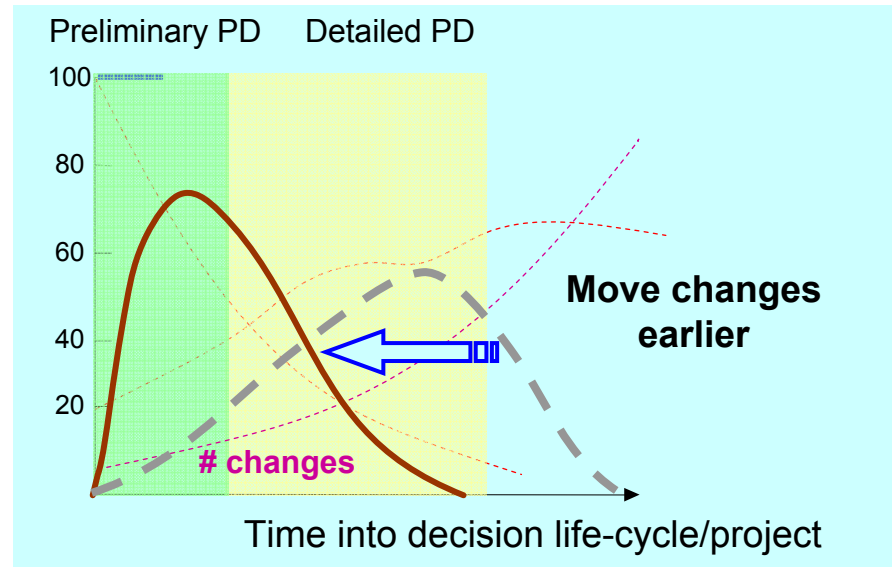
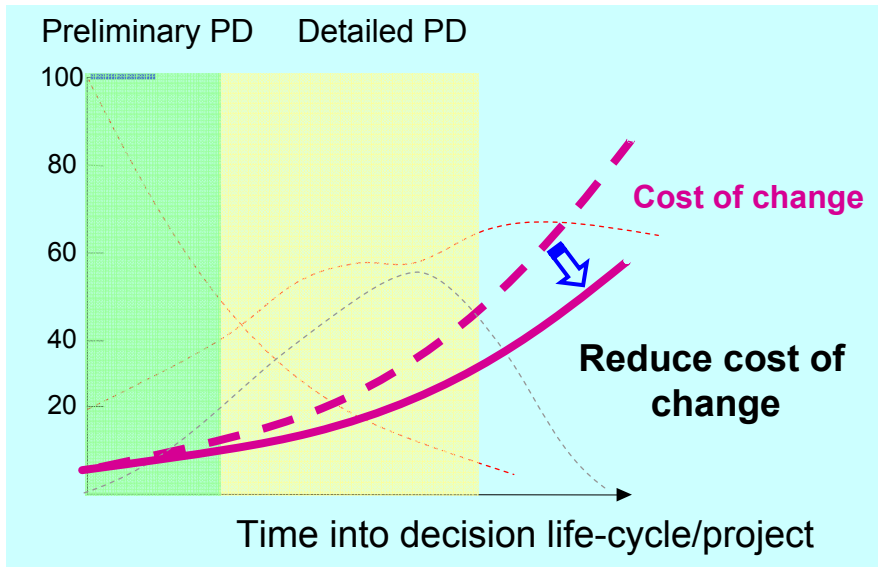
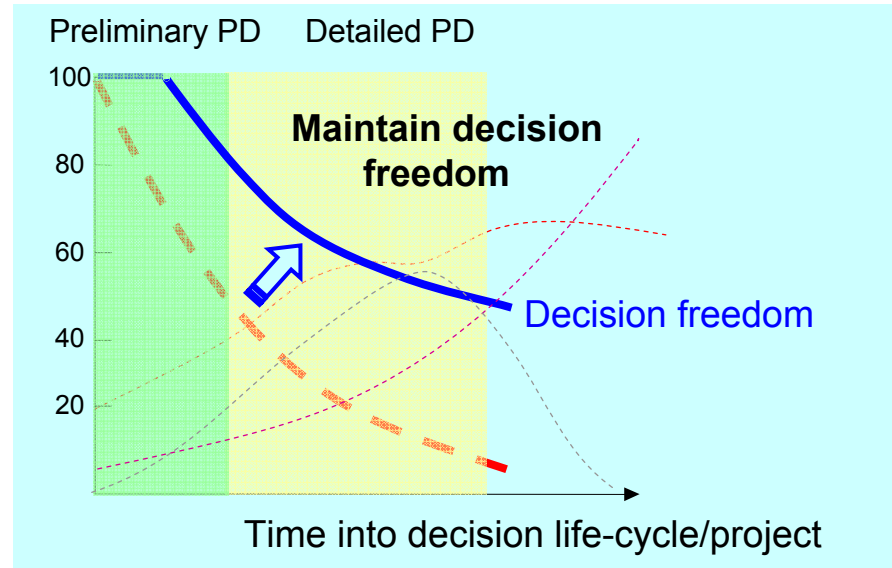
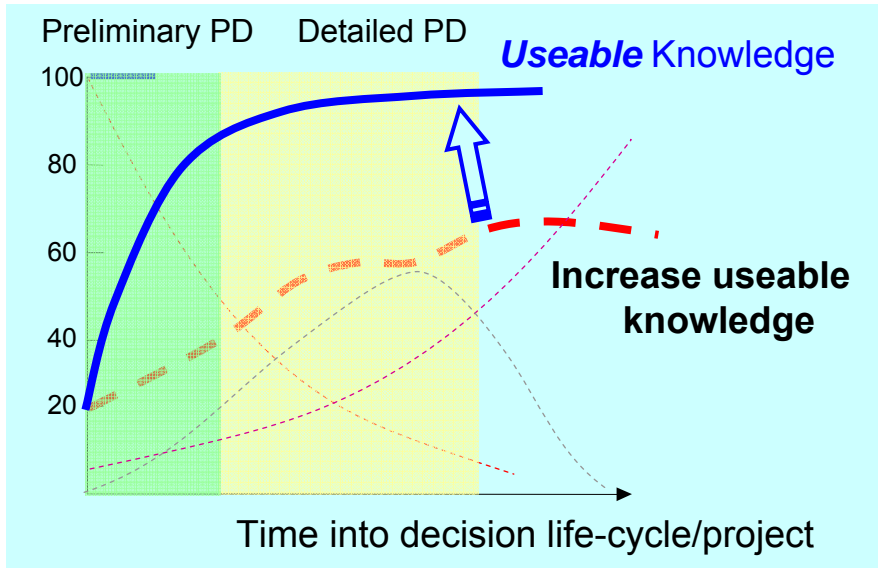


(less) Familiar figure

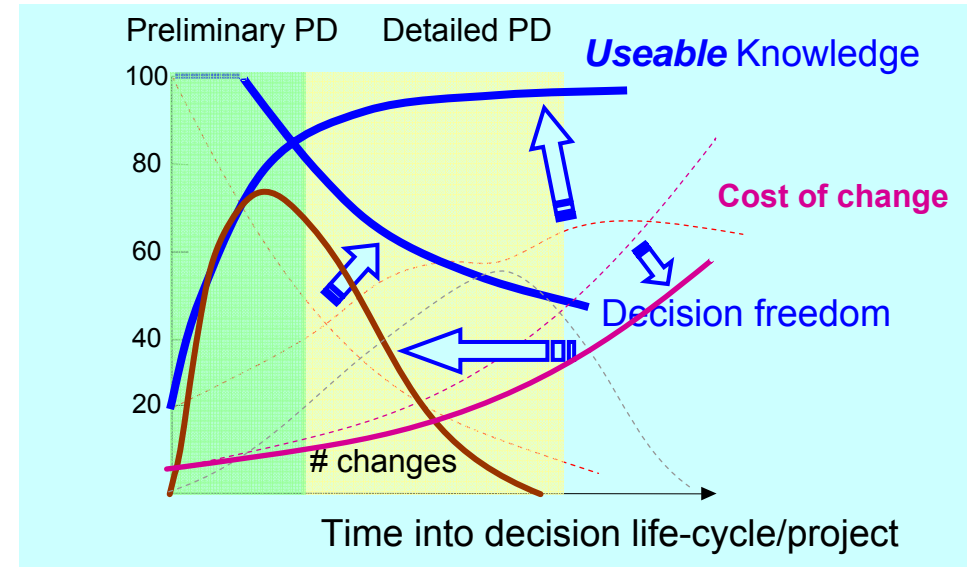
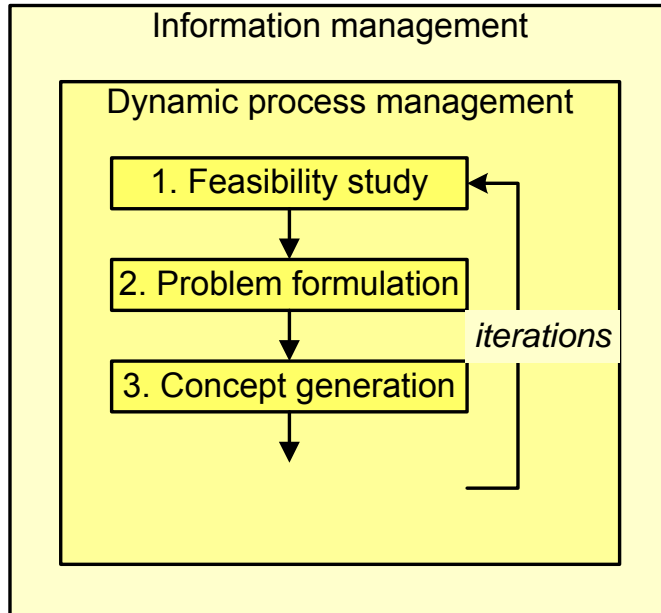
תוצאות הרסניות

- אין חופש פעולה לבצע שינויים כשהם נדרשים – עלות גבוהה, זמן פיתוח מתמשך, סיכון גדל
- ידע נוצר אינו מנוהל – הפסד הזדמנויות, בזבוז משאבים

The product development **paradox (PDP) (3)**



פרדוקס האיכות: מעקרונות לגישת פתרון



תהליך פיתוח אידאלי

גישה

- שימוש בשיטות תכן משולבות
- ניהול דינמי של תהליך הפיתוח
- ניהול ידע ע"י שלוב השיטות בתהליך סדור

מטרות

- העשרת הידע הזמין – אינטגרציה של מקורות רבים וניהול הידע
- ניהול דרגות החופש
- הקטנת עלות שינויים
- יכולת לבצע שינויים בתחילת התהליך בעלות נמוכה – מינוף שינויים כהזדמנויות למידה ויצירת ידע נוסף

יישום הגישה

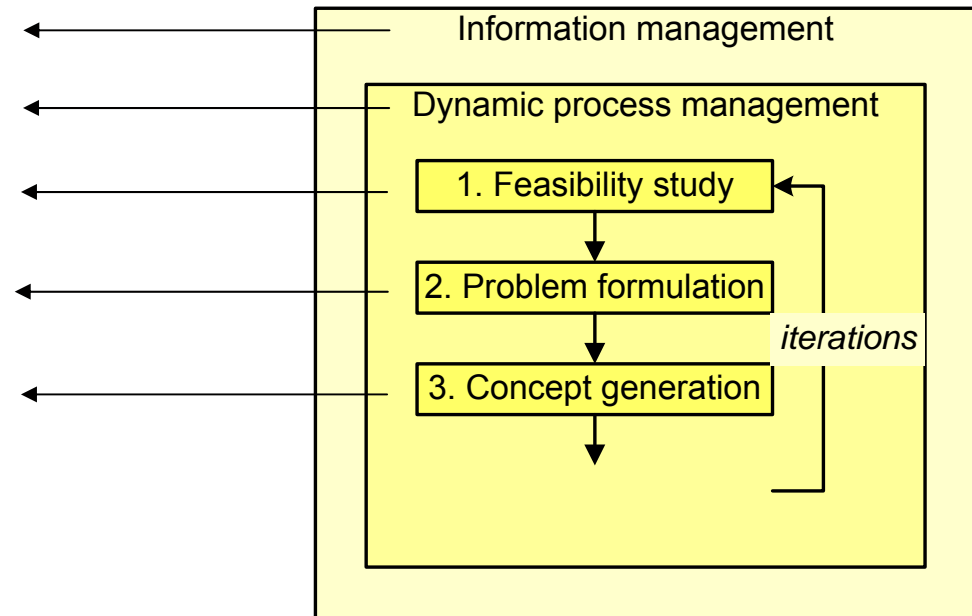
***n*-dim** (n dimensional information modeling)

DPDP (dynamic product development process management)

RQFD (Resource/Robust QFD)

WP (Wicked Problem formulation)

APSOS (Concept generation)



עקרונות

- חסינות הפתרון ע"י ביצוע ניתוחי רגישות
- משוב מידי מפורט מאפשר סבבי הגדרת בעיה ופתרון מהירים (e.g., WP+SOS)
- קלות שימוש בגלל שימוש בנתונים גסים

גישה

- שימוש בשיטות תכן משולבות
- ניהול דינמי של תהליך הפיתוח
- ניהול ידע ע"י שלוב השיטות בתהליך סדור

Acknowledgements:

DPDP: Arie Karniel

RQFD: Eyal Levy, Amir Paz

WP, *n*-dim: Prof. Eswaran Subrahmanian, *n*-dim group

SOS: Dr. Amir Ziv-Av

AP: Dr. Avner Engel

APSOS: Dr. Avner Engel, Yuri Belsky

System architecture

- Selection of the types of system elements, their characteristics, and their arrangement

- SoS

- ◆ **hierarchical**
- ◆ **Interacting**
- ◆ **complex**

- Environment:

- Economic crisis
- Oil price fluctuating
- Intense competition

[INCOSE SE Handbook]

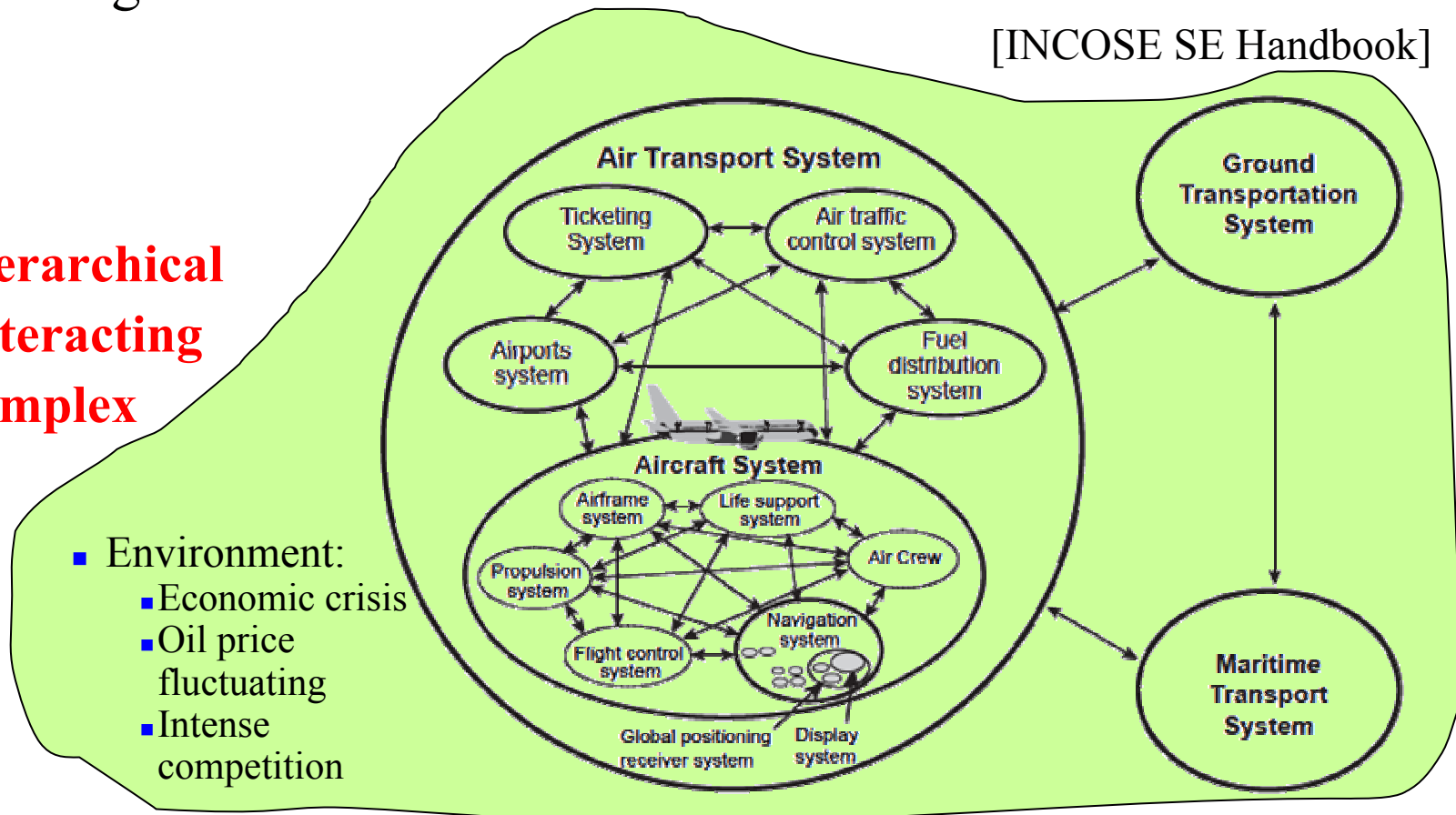
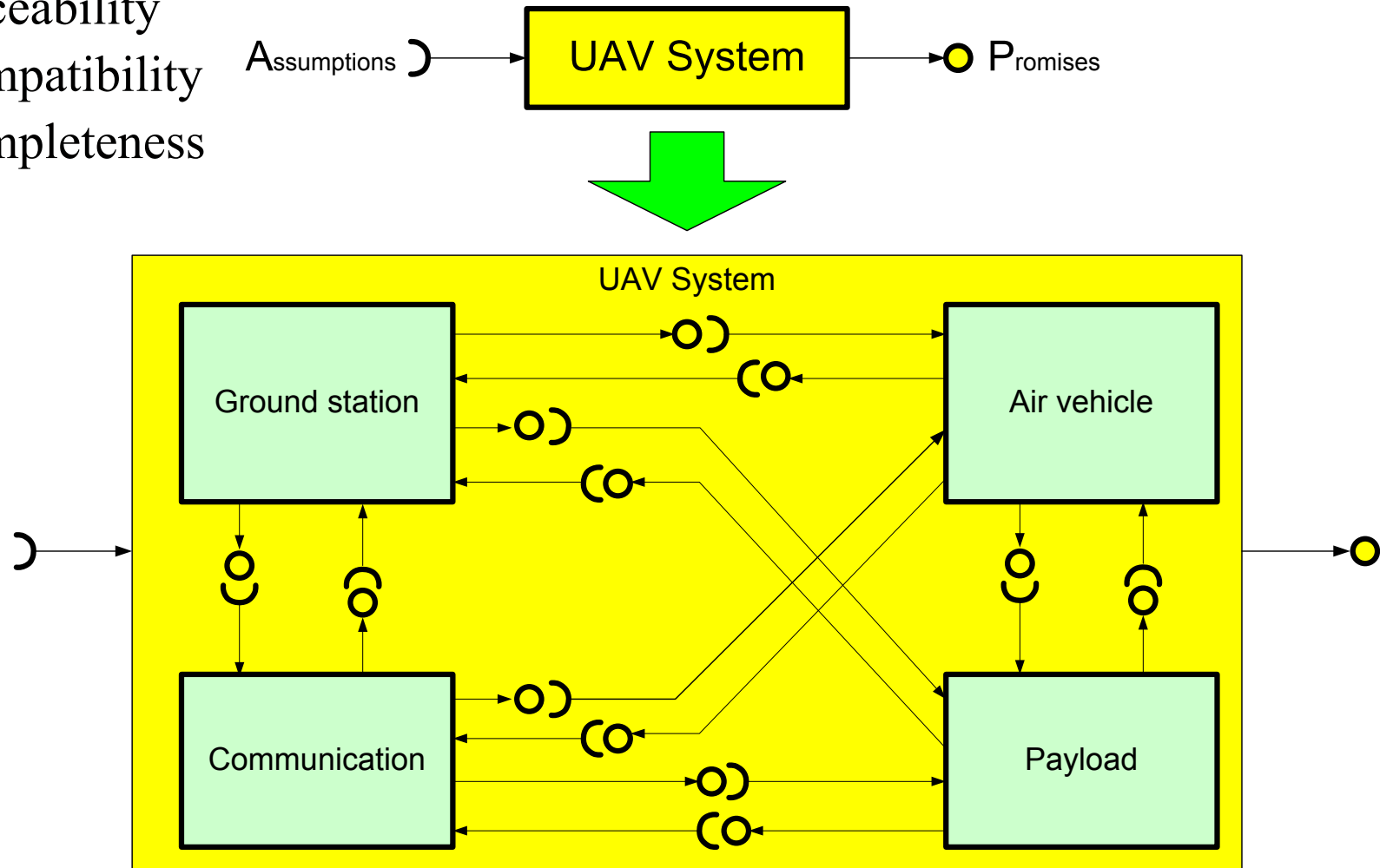


Figure 2-1 Example of the multitude of perceivable systems-of-interest in an aircraft and its environment of operation within a Transport System-of-Systems⁸

AP: Assumption Promises (Dr. Avner Engel)

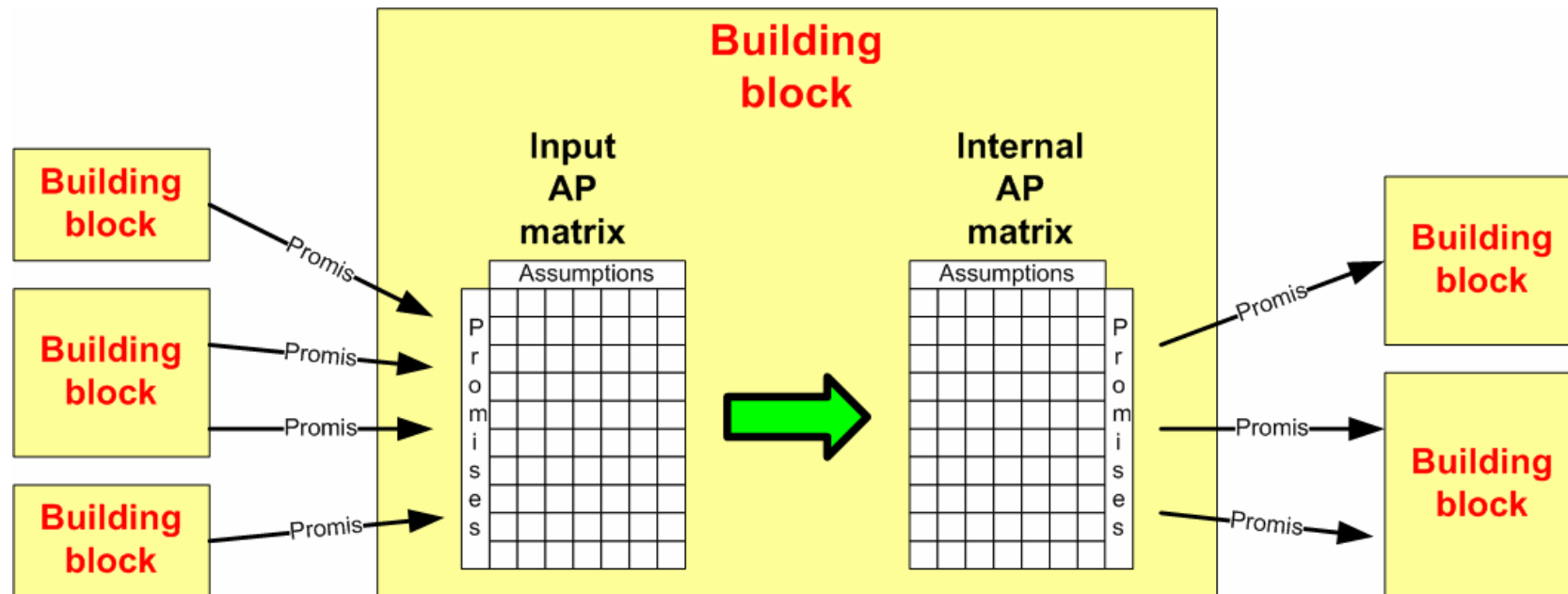
■ Ensure

- ◆ traceability
- ◆ compatibility
- ◆ completeness



AP: Assumption Promises (Dr. Avner Engel)

- External and internal interaction between assumption and promises



SOS – *robust product concept innovation*

- **Subjective Objective System** for Optimal Robust Concept Generation
- PhD work of **Amir Ziv Av**, being continually extended in different directions
- Used in [Ziv Av Engineering](#)

- References:
 - ◆ Y. Reich and A. Ziv-Av, “**A comprehensive optimal product concept generation framework**,” in *Proceedings of the 15th International Conference on Design Theory and Methodology (DTM)*, (New York, NY), ASME, 2003.
 - ◆ A. Ziv-Av and Y. Reich, “**SOS – Subjective objective system for generating optimal product concepts**,” in *CD-ROM Proceedings of the 14th International Conference on Engineering Design (ICED)*, The Design Society, 2003.
 - ◆ A. Ziv-Av and Y. Reich, “**SOS – Subjective objective system for generating optimal product concepts**.” *Design Studies*, 2005.
 - ◆ Y. Reich and A. Ziv-Av, “**Robust product concept generation**”, in *CD-ROM Proceedings of the 15th International Conference on Engineering Design (ICED)*, The Design Society, 2005.

SOS and robust product concepts

- Inputs to SOS:
 - ◆ **Product objectives**
 - ☞ Customer requirements
 - ☞ Manufacturer objectives
 - ☞ ... government regulations, etc.

 - ◆ **Building blocks**
 - ◆ **Constraints**

 - ◆ **Influence of building blocks on attaining product objectives**

Example car design: Product objectives

- Customer – **objective**
 - ◆ Stability and handling
 - ◆ Safety in accidents
 - ◆ Low ownership cost
 - ◆ ...
- Manufacturer – **subjective**
 - ◆ Minimal investment/risk in development (for Peugeot, Citroen)
 - ◆ Minimal mass production cost
 - ◆ Ease of maintenance
 - ◆ ...
- Objectives have relative weight w which define a market segment

Example car design: Building blocks (BB)

- Front engine
 - Rear engine
 - Driver before front wheels
 - Driver behind front wheels
 - Front wheel drive
 - Rear wheel drive
 - 4x4 wheel drive
 - Central transmission
 - Rigid axels
 - Independent suspensions
-
- Value of building blocks – $D = 0,1$

Example car design: Constraints b/w BBs

1. Front engine **or** Rear engine
 $(\text{Front engine}) + (\text{Rear engine}) = 1$
2. Front, Rear, **or** 4x4 wheel drive
 $\text{Front} + \text{Rear} + 4x4 = 1$
3. 4x4 drive **requires** central transmission **and vice versa**
 $(4x4 \text{ drive}) - (\text{central transmission}) = 0$
4. Driver behind front wheels **and** Front wheel drive **require** independent suspension
 $(\text{Independent suspension}) - ((\text{Driver behind front wheels}) + (\text{Front wheel drive})) \geq -1$

From our experience in numerous projects, all constraints could be represented by simple linear expressions

Example car design: Influence of BBs on product objective

Minimal investment/risk in development (for Peugeot, Citroen)

- 1st order

$$LI(\text{Front engine}) = 1$$

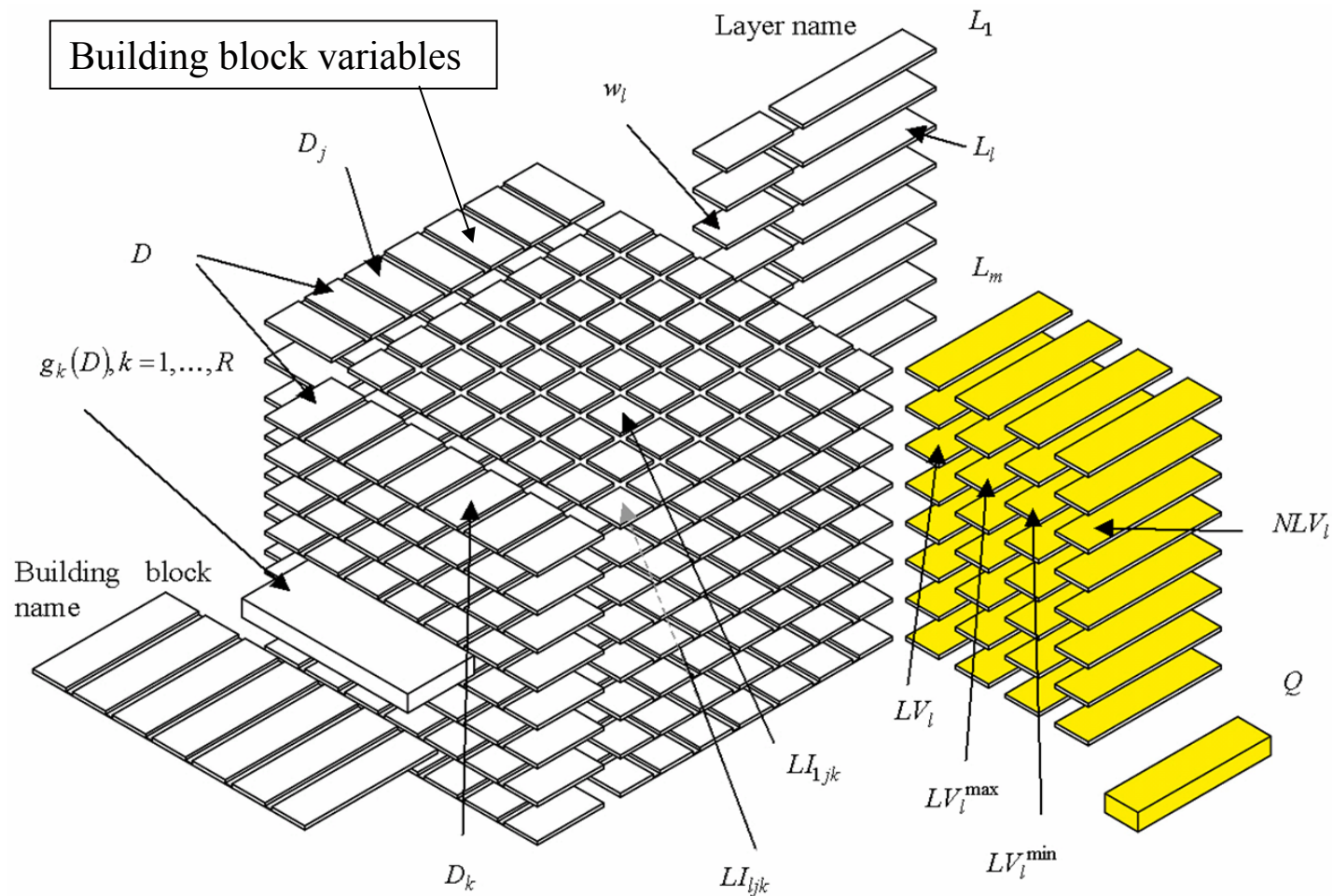
$$LI(\text{Rear engine}) = -1$$

- 2nd order

$$LI(4x4, \text{central transmission}) = -1$$

$$LI(\text{Rear engine, Front wheel drive}) = -1$$

Organization of information into layers



Mathematical Formulation (basic form)

$$\max Q = \sum_{l=1}^m w_l \cdot NLV_l$$

$$NLV_l = \frac{LV_l - LV_l^{\min}}{LV_l^{\max} - LV_l^{\min}}$$

$$LV_l = \sum_{j=1}^n D_j \cdot \sum_{k=1}^n LI_{ljk} \cdot D_k$$

subject to

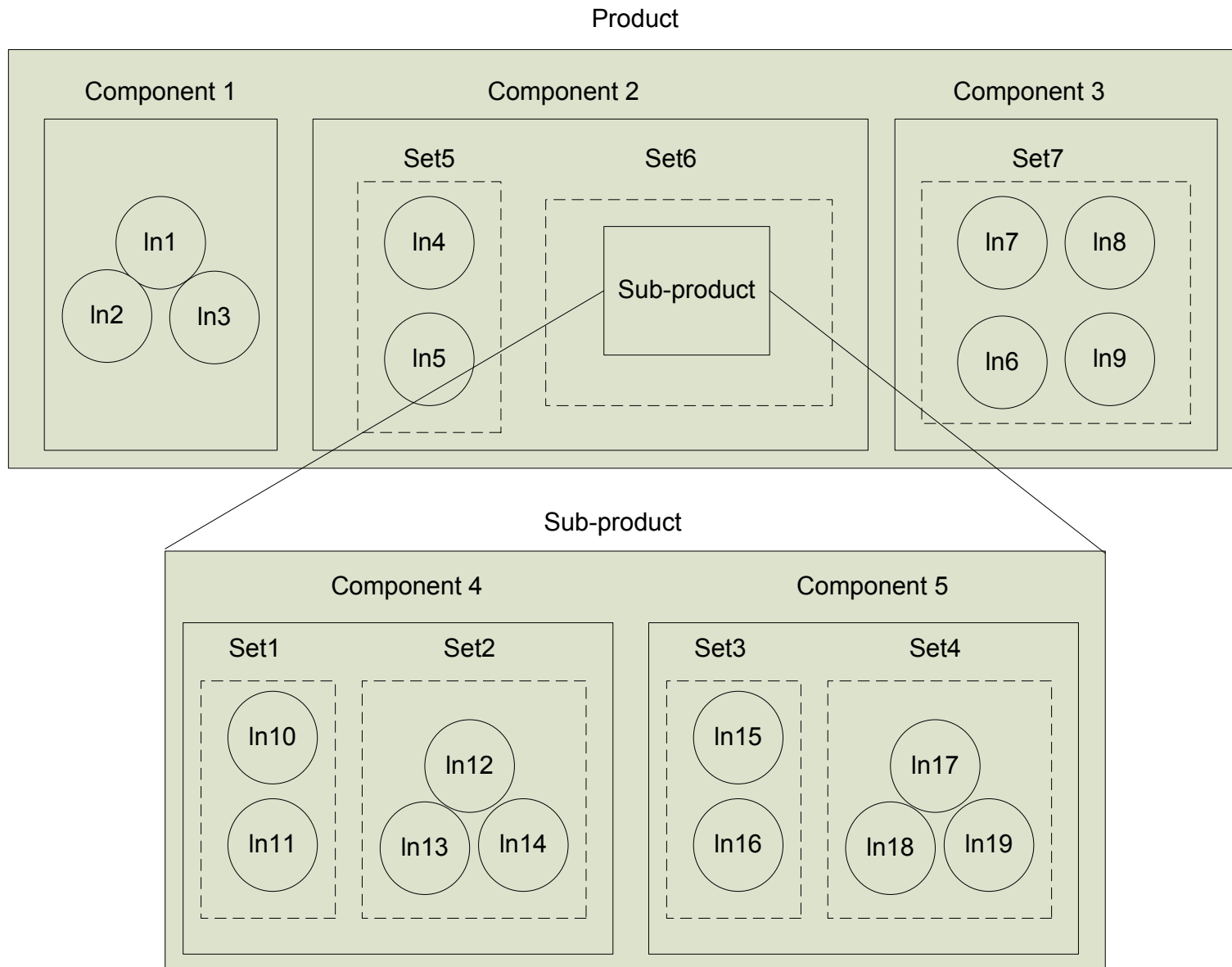
$$g_k(D_1, \dots, D_n) \begin{matrix} \leq \\ = \\ \geq \end{matrix} b_k, k = 1, \dots, R$$

$$D_j = 0, 1, j = 1, \dots, n \quad \sum_{l=1}^m w_l = 1$$

The user of SOS is unaware of this formulation.

After entering the data, SOS outputs the optimal concept.

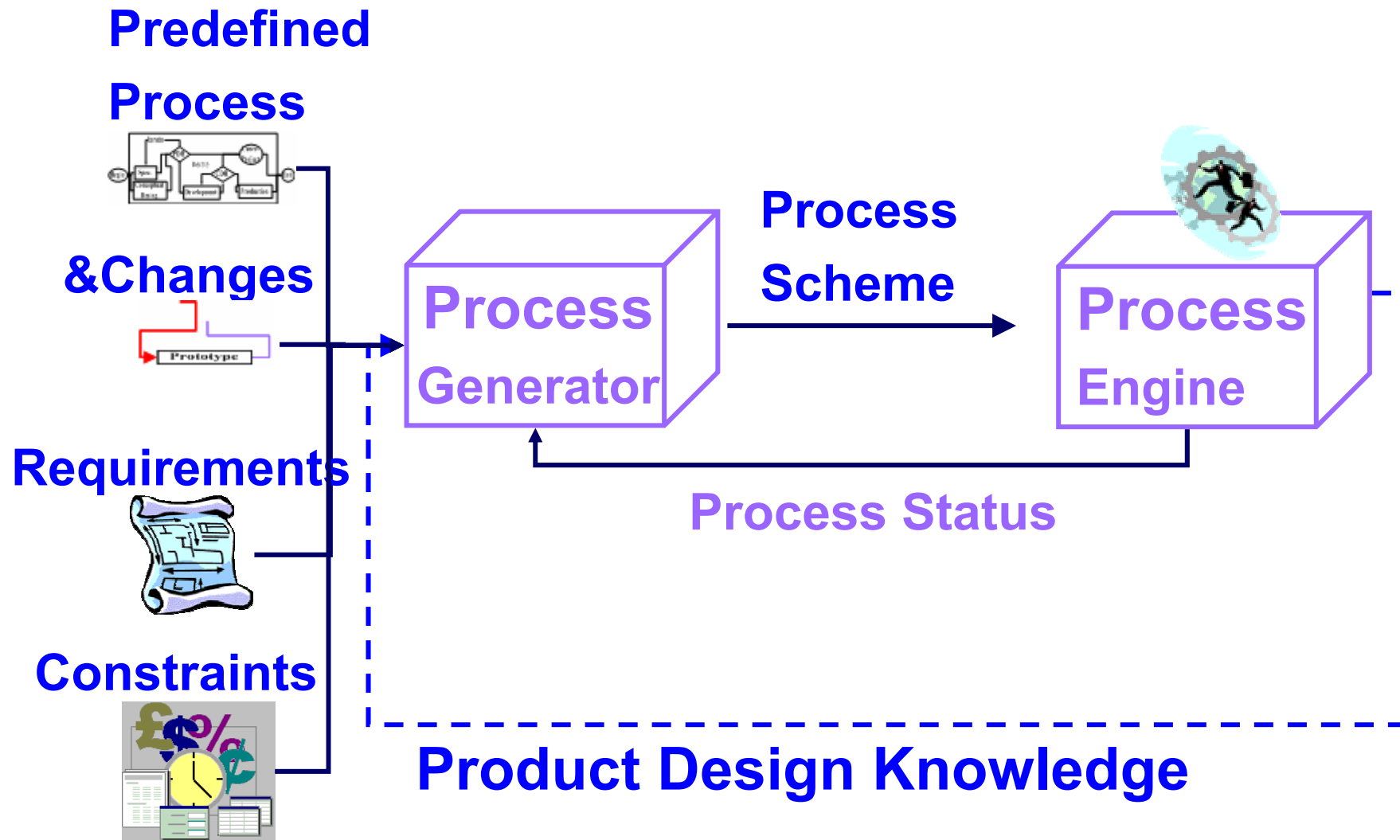
APSOS: integrating SOS with AP (Yuri Belsky)



Dynamic product development processes (Dr. Arie Karniel)

- Need to account for dynamic system development projects
 - Constantly evolving in an unpredictable manner
-
- ⇒ Make sure fast changes are sound
 - ⇒ Plan based on simulations of randomized events (albeit from a predictable ensemble)

Dynamic new Product Development Processes (DPDP)



DPDP

■ Input

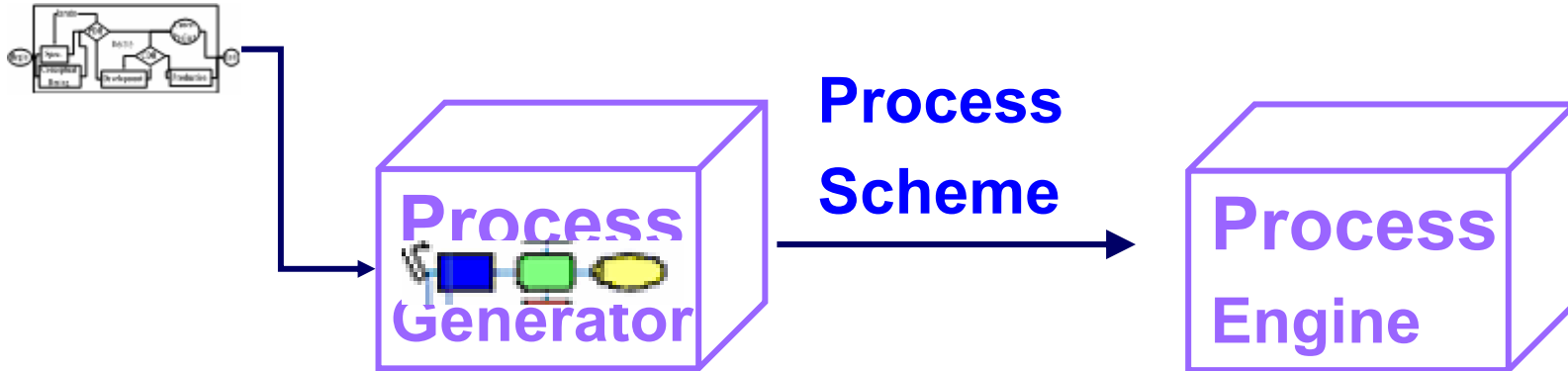
- ◆ Predefined process scheme
- ◆ Various constraints
- ◆ *Real-time* project status and knowledge

■ Output

- ◆ New process scheme optimized to desired objectives
- ◆ Record of design process

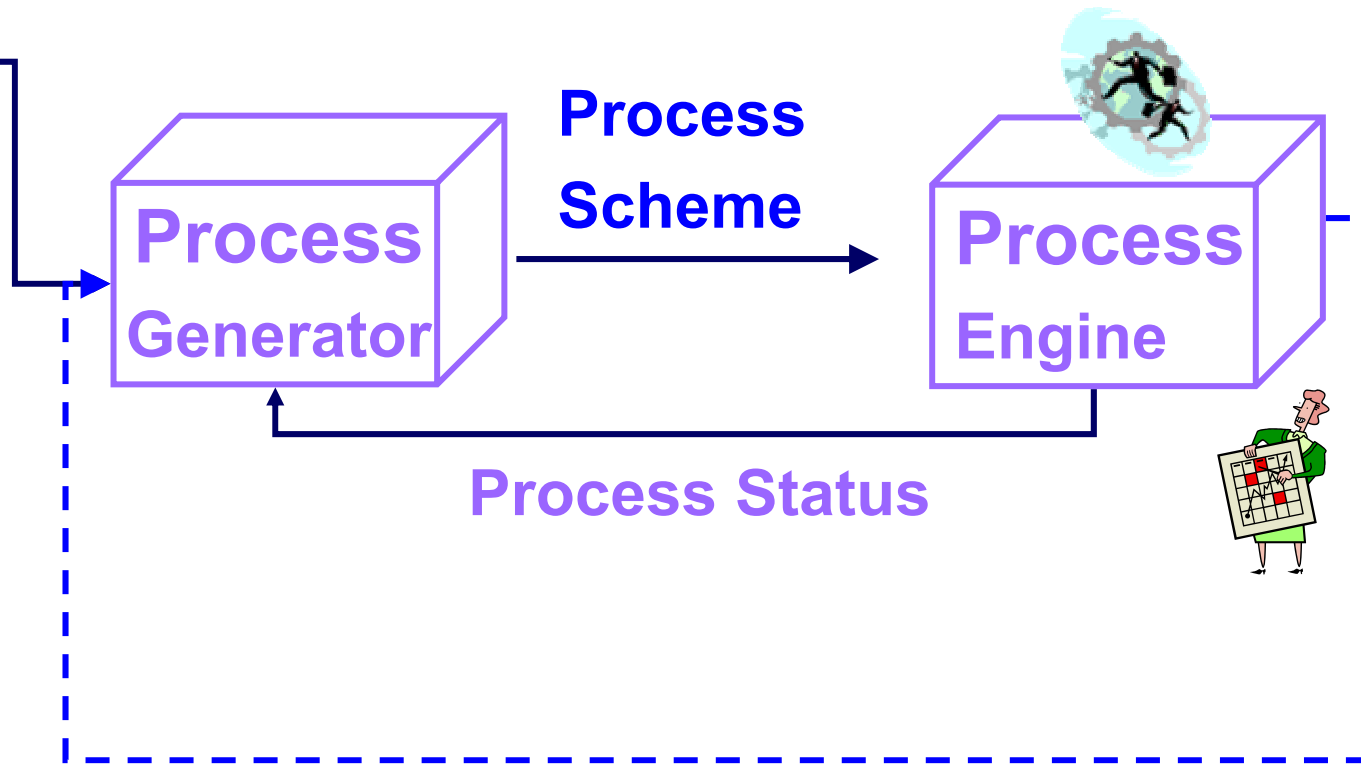
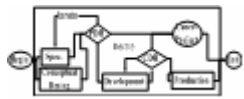
DPDP: Framework

**Predefined
Process**



DPDP: Framework

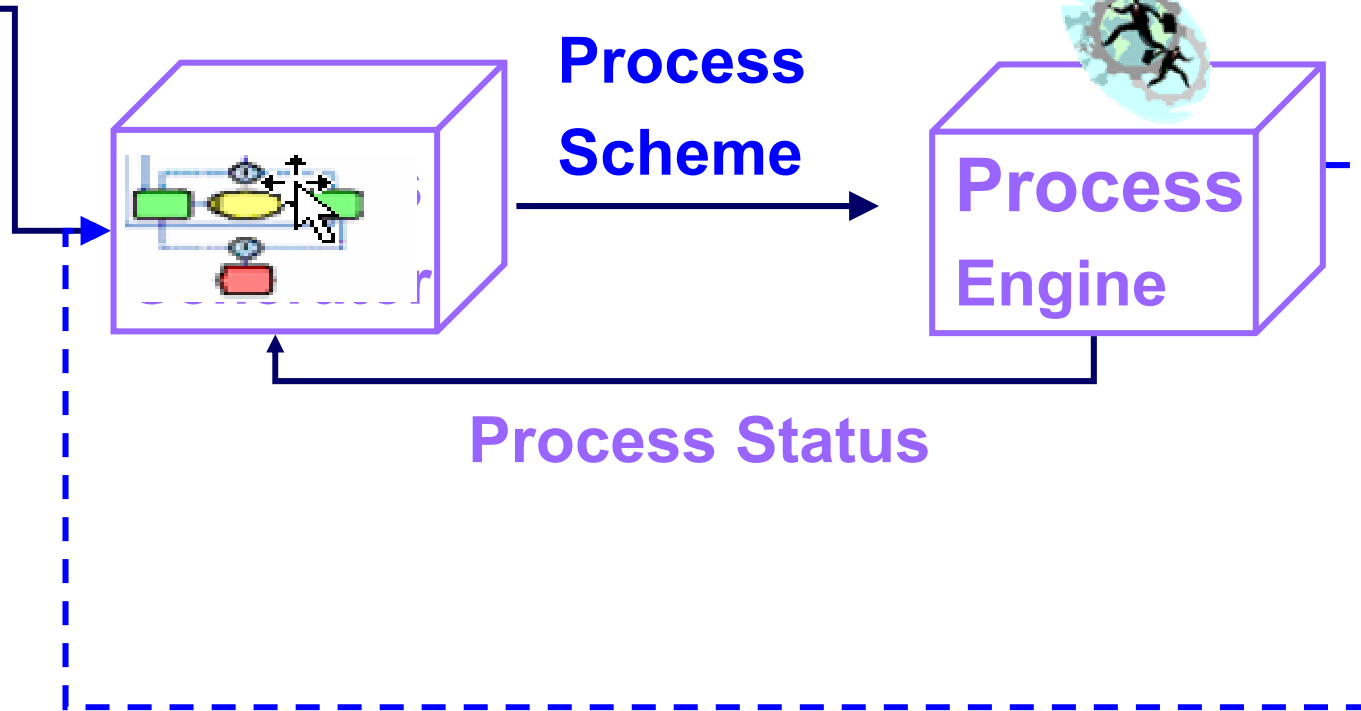
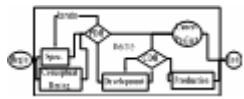
**Predefined
Process**



Product Design Knowledge

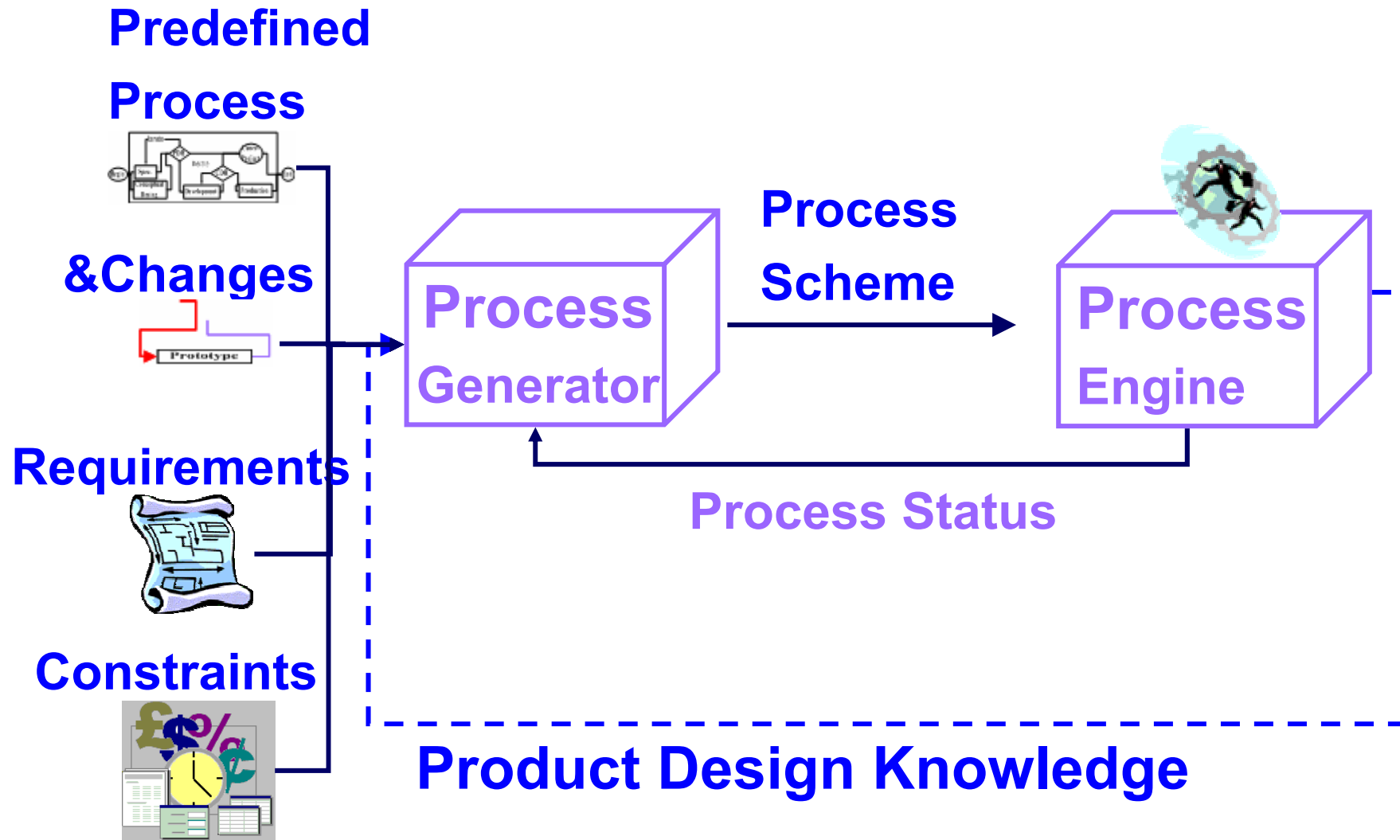
DPDP: Framework

**Predefined
Process**



Product Design Knowledge

DPDP: Framework

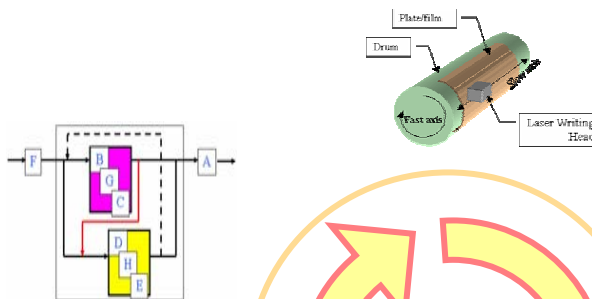


DPDP: Process Planning Cycle

From product knowledge to process plan

Define product Components

Planned Process

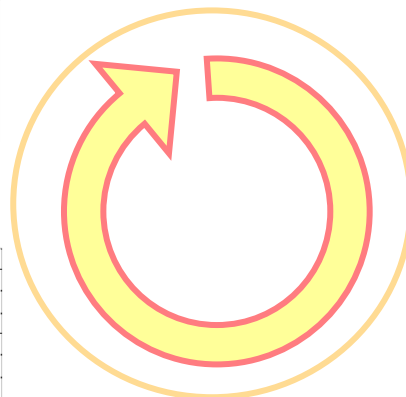


Define Component parametric links

	A	B	C	D	E	F	G	H
A								
B								
C								
D								
E								
F								
G								
H								

Rearranging DSM

	F	B	G	C	D	H	E	A
F	0.22							
B		0.00	0.13	0.04				
G	0.04	0.30	0.00	0.00				
C		0.17	0.39	0.00	0.09			
D					0.00	0.04	0.17	
H	0.09		0.13	0.22	0.09	0.00	0.13	
E					0.43	0.22	0.00	
A	0.17	0.52	0.00	0.22			0.04	0.00



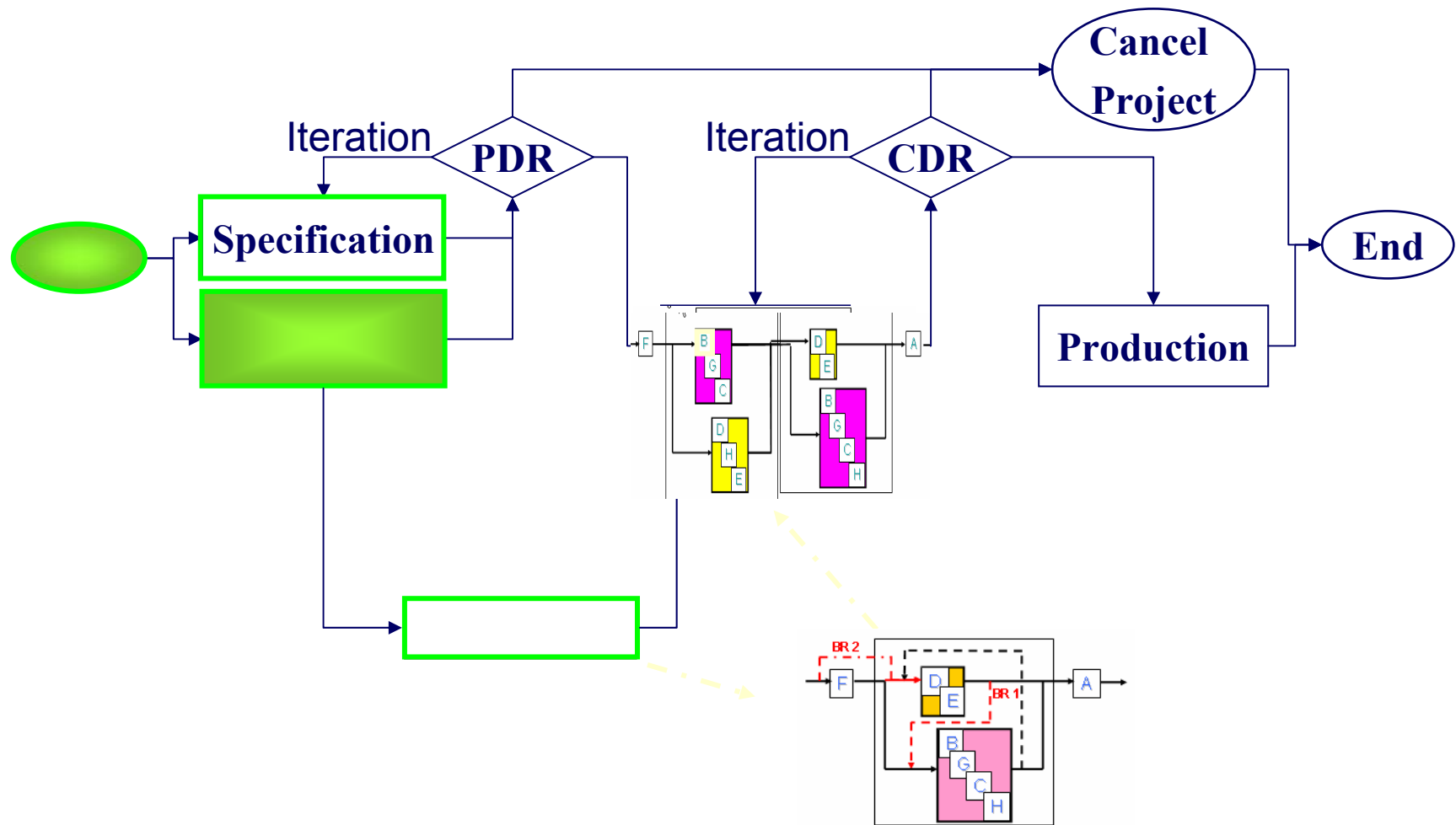
	A	B	C	D	E	F	G	H
A	1	5	2	3	1			
B		1						
C	4		1					
D				1				
E					10			
F						1		
G							1	
H		5	2	3	2	3		

DSM Representation

	A	B	C	D	E	F	G	H	
A	0	0.52	0.22		0.04	0.17	0.00		
B		0	0.04				0.13		
C			0.17	0	0.09		0.39		
D				0	0.17			0.04	
E					0.43	0		0.22	
F						0	0.22		
G			0.30	0.00			0	0.04	
H				0.22	0.09	0.13	0.09	0.13	0

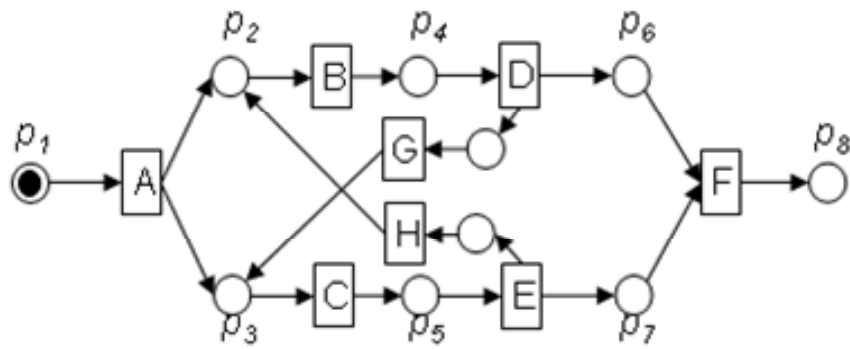
Probability DSM

DPDP: New product process example

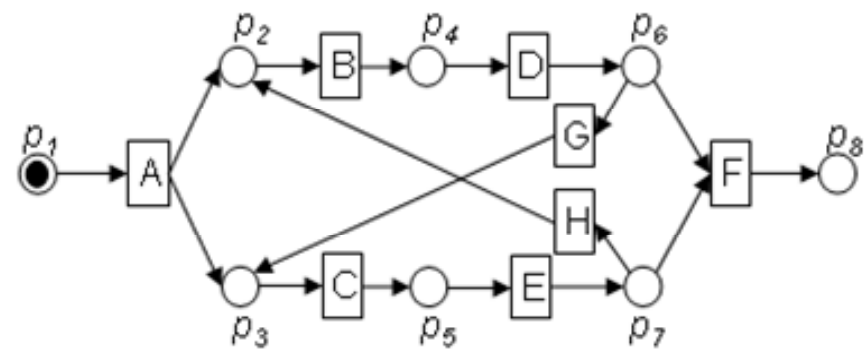


DPDP: sound and unsound processes

- Changes in the process scheme must lead to sound processes



(a) Live lock process



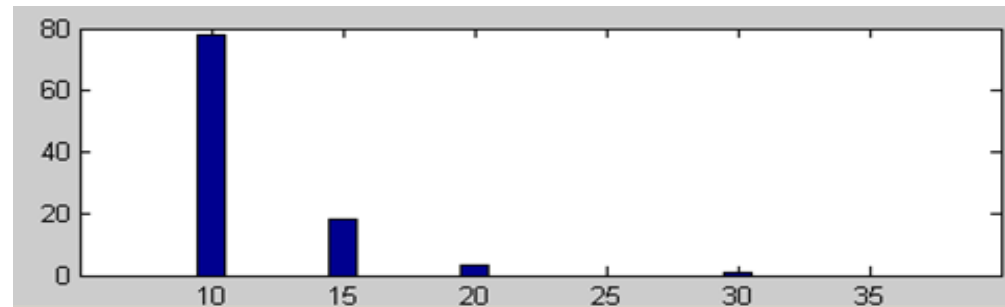
(b) Sound process

Iterations of parallel paths

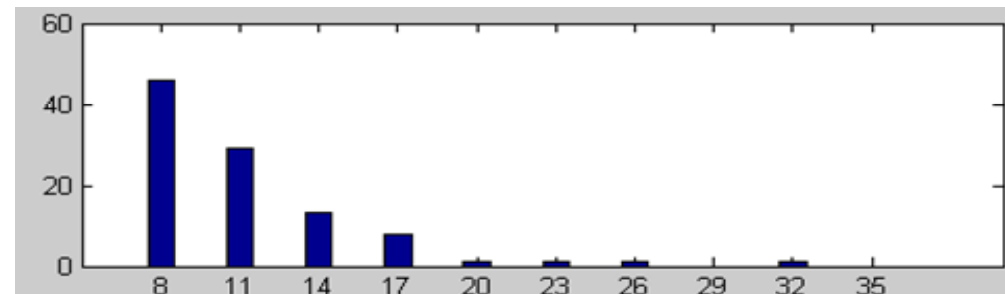
DPDP: Process simulations and decision making

- Process simulations of random changes allows making better process design decisions

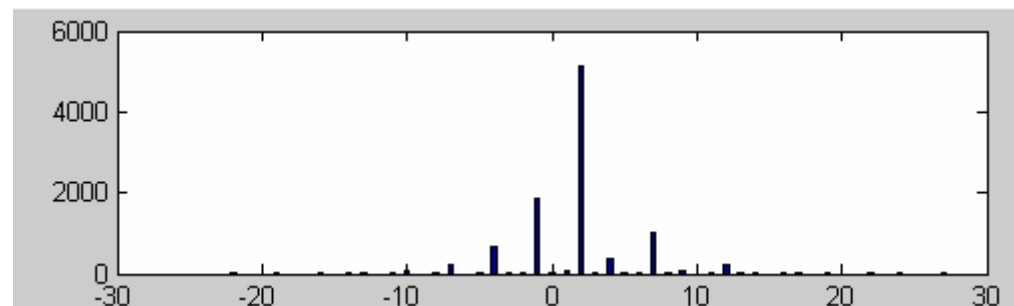
P1 – Serialized



P2 – Design block



Difference function



Conclusions

- **Product development paradox**

- **Integrated suite of tools for architecture development and dynamic process management**
 - ◆ SOS moves robustness into conceptual design
 - ◆ Robustness is addressed by systematically simulating conceptual design with varying conditions and maintaining traceability and compatibility between components
 - ◆ DPDP supports dynamic changes.

Additional information:

email: yoram@eng.tau.ac.il

web: www.eng.tau.ac.il/~yoram

google.com: yoram reich

Course Material: Product development: Introduction and methods

1. A. Karniel and Y. Reich, Managing dynamic new product development processes, CD proceedings of the *INCOSE International Symposium (INCOSE 2007)*, San Diego, CA, 2007. (DPDP)
2. A. Karniel and Y. Reich, Coherent interpretation of DSM plan to PDP simulation, in *CDROM Proceedings of the 16th International Conference on Engineering Design (ICED)*, The Design Society, 2007. (DPDP)
3. A. Karniel and Y. Reich, “From DSM-based planning to Design Process Simulation: A review of process-scheme logic verification issues”, *IEEE Transactions on Engineering Management*, in press, 2009. (DPDP)
4. E. Kolberg, Y. Reich, and I. Levin, Design of design methodology for autonomous robots, *RoboCup 2007*, Atlanta, 2007.
5. E. Kolberg, Y. Reich, and I. Levin, Express engineering change management, in *CDROM Proceedings of the 16th International Conference on Engineering Design (ICED)*, The Design Society, 2007.
6. Y. Reich and E. Levy, Managing product design quality under resource constraints, *International Journal of Production Research*, 42(13):2555-2572, 2004. (RQFD)
7. Y. Reich, E. Kolberg, and I. Levin, Designing contexts for learning design, *International Journal of Engineering Education*, 22(3):489-495, 2006.
8. Y. Reich and A. Paz, Managing product quality, risk, and resources through resource quality function deployment, *Journal of Engineering Design*, 19(3):249-267, 2008. (RQFD)
9. Y. Reich and A. Ziv-Av, Robust product concept generation, in *CDROM Proceedings of the 15th International Conference on Engineering Design (ICED)*, The Design Society, 2005. (robust concept design using SOS)
10. Y. Sered and Y. Reich, Standardization and modularization driven by minimizing overall process effort, *Computer-Aided Design*, 38(5):405-416, 2006.
11. E. Subrahmanian and Y. Reich, Advancing Problem Definition and Concept Generation for Improved Product Life Cycle, *International Conference on Trends in Product Life Cycle, Modeling, Simulation and Synthesis, PLMSS-2006*, 18-20 December, Bangalore, India, 2006. (Invited Talk) (WP + SOS)
12. A. Ziv-Av and Y. Reich, SOS – Subjective objective system for generating optimal product concepts, *Design Studies*, 26(5):509-533, 2005. (SOS)
13. Y. Reich, Preventing Breakthroughs from Breakdowns, *Proceedings of the 9th Biennial ASME Conference on Engineering Systems Design and Analysis ESDA2008*, Haifa, Israel, 2008. (describes the PDP)

Thank you for your attention

פרופ' יורם רייך – רקע

- תואר ראשון (בהצטינות יתרה) ושני (בהצטינות) בהנדסה מכנית, אונ' תל-אביב
- 6 שנים בחיל הים בתכנון הנדסי כולל הקמת מדור מו"פ ותיב"מ
- תואר שלישי בשימושי בינה מלאכותית בהנדסה, Carnegie Mellon University
- עבודה ב- Carnegie Mellon University, Engineering Design Research Center ;
- Duke University ; שבתון ב- Stanford University, Design Center
- בעבר – חבר הנהלה ויו"ר התא הישראלי של האיגוד הבין לאומי
SME – Society of Manufacturing Engineers
- כיום – פעיל בתא הישראלי של האיגוד הבין לאומי להנדסת מערכות
INCOSSE-IL האיגוד הישראלי להנדסת מערכות
- פרסום למעלה מ- 170 מאמרים מדעיים
- עורך ראשי של הירחון המדעי *Research in Engineering Design*
- חבר מערכת ב- 5 ירחונים מדעיים אחרים
- יו"ר משותף של התא לתורת תכן של ה- *Design Society*
the Design Society a worldwide community
- חבר ועדות מדעיות של כנסים רבים בעולם
- ראש מסלול תכן ותיב"מ, תוכנית לימודי תואר ראשון בהנדסה מכנית, אונ' תל אביב
- ראש המעבדה למערכות ממוחשבות, אונ' תל אביב
- התמחות בשיטות תכן הנדסי, ניהול ידע, מערכות מידע בהנדסה, בינה מלאכותית, כריית נתונים, תיב"מ

