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Managing the competencies of team members in design projects through multi-period task assignment

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Outline

1. Motivations and context
2. Definitions and assumptions
3. Formulation and solving of the HR allocation problem
4. Interpretation of computational results
5. Conclusion and future work

Industrial context : complex systems engineering

Design managers and project managers need to improve sustainable performance of design projects

⇨ Human resources' competencies = strategic assets

However …

- Products
  - High number of components, needs, technologies …
  - Increasingly changing
- Processes
  - High number of multidisciplinary processes
  - Frequent re-engineering ➔ new processes, tasks
  - + New tools and methods
- Communities
  - High number of various skill networks: functional departments, project teams, communities of practice, virtual organizations, long-term partnerships …
  - Rapid learning (individual, organizational)

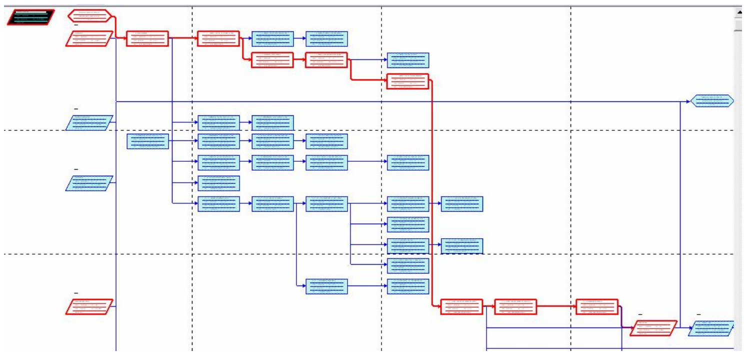
➔ determine goals concerning competency development, and

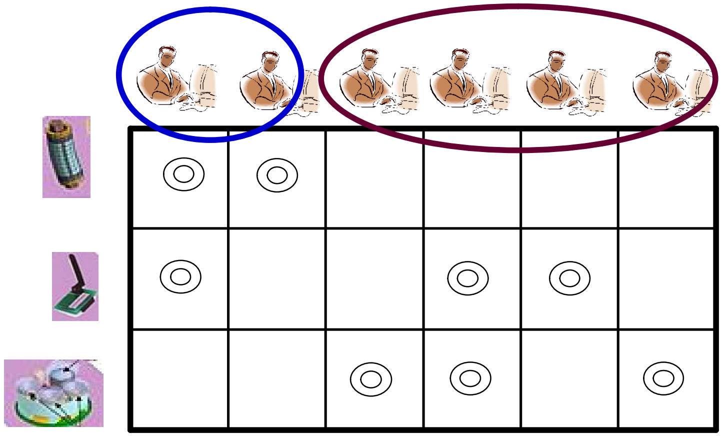
➔ define plans to help designers to achieve these goals

Research context: competency management

(Boucher et al., 2007)

Strategic	Identification of core competencies
Organizational	HR allocation
Operational	performance evaluation





Related work

Allocation	Mono-period	Multi-period
with static competency modelling	[Caron et al., 1999] [Campbell et Diaby, 2002] [Eiselt et Marianov, 2008] …	[Miller et Franz, 1996] [Bellenguez-Morineau, 2006] [Corominas et al., 2006]
with dynamic competency modelling	[Sayin et Karabati, 2007]	[Gutjahr et al. 2008, 2009] [Fowler et al., 2008]

Multi-period HR allocation [Gutjahr et al., 2008]

- project selection in a project portfolio (strategic decision)
- evolution of competency by introducing learning and forgetting effects, but no competency-based objective.

Problem

- Given a project schedule,
- the multi-period multi-project HR allocation problem,
  - minimize global project costs and
  - take into account defined objectives in competency development.

Key concepts

Two types of tasks:

- a *generic task* represents a design task that has been performing in projects in a recurrent basis.
- a *specific task* is the occurrence of the generic task i at the period k for the project l.

➔ A generic class corresponds to a class of specific tasks. Their specificity depends on the actual conditions and requirements of each project.

Competency is related to a generic task ; the matching between a specific task and an actor depends on his/her competency related to this task.

Concept of knowledge, in a general sense ➔ scientific knowledge, practical knowledge (that is, skills), interpersonal attitudes, personal traits ...

Key concepts

A generic task is described by a set of knowledge and *required* knowledge scores, which are considered as reference values to perform this generic task. This value depends on the RD strategy that is fixed by the RD manager.

A resource is described by a set of knowledge and *acquired* knowledge scores, which represent the level of knowledge that are acquired by this resource *j* at the period *k*.

The scores of relevant knowledge are assessed by experts or department managers.

Key concepts

The *matching index* represents the degree of compatibility between the scores of knowledge c that are required by a task i and the scores of knowledge c that are acquired by an actor j.

$$V3_{i,j}^{k,l} = r1_{i,\bullet}^{k,l} \circ r2_{\bullet,j}^{k-1} = 1 - \frac{\sum_{c=1}^{O} \max(0, r1_{i,c}^{k,l} - r2_{c,j}^{k-1})}{\sum_{c=1}^{O} r1_{i,c}^{k,l}}$$

It represents the estimation of the actor's efficiency for achieving this task.

The *competency score for an employee j*, is related to the generic task.

Assumptions

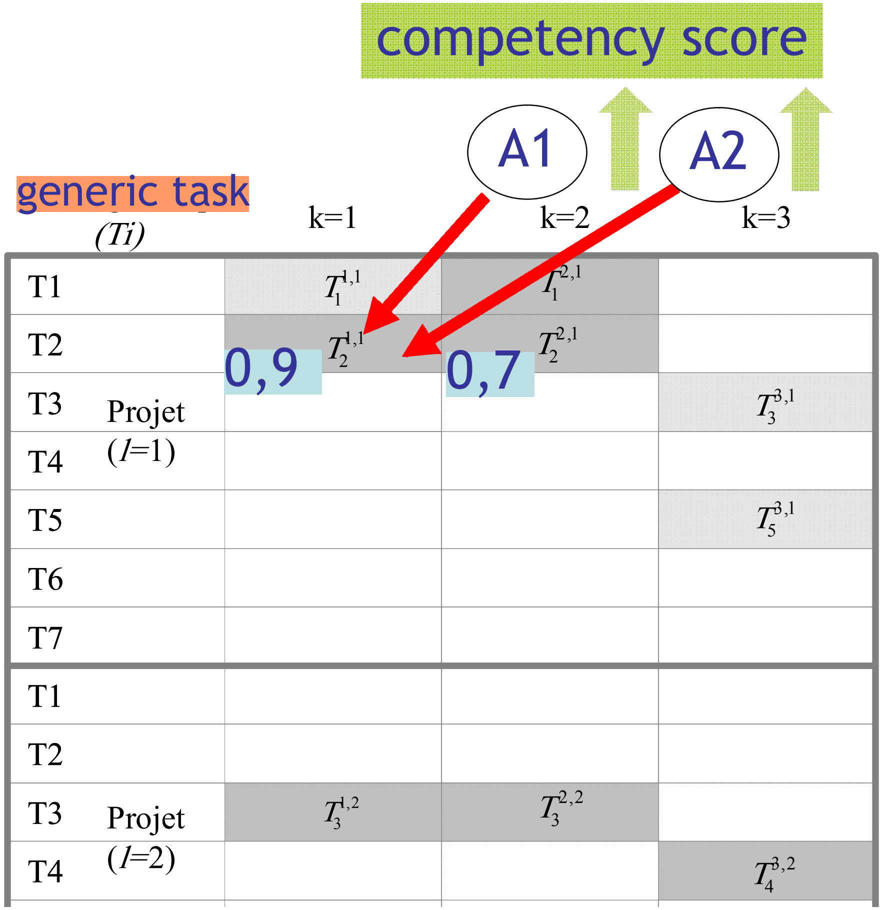
- Ways of developing competencies?
  - courses (in a class, or with e-learning ...)
  - training in virtual situations (simulation)
  - training in actual situations with the help of a trainer, an expert ➔ "learning by doing" ⊕ "reflexive practitioner"

- Similarly to [Gutjahr 2008; Fowler 2008], we assume :
  - the competency score of the person who has been assigned to a task increases when he/she activates this competency.
  - the competency score will decline (in accordance to a knowledge depreciation rate) if he / she has not been assigned to a specific task corresponding to this competency.

➔ competency development depends on resource allocation decisions

Assumptions

- Task schedule = given data
- Competency scores that are required by tasks depend on the allocation period
  - More than one actor may contribute to achieve a specific task
- After each allocation, competency scores are computed
  - The actual processing time depends on the actor's efficiency that is linked to the matching index between the actor and this task
- Each task is successfully performed



Structure of the RH allocation problem

Input data

- { Task T_i } , i=1 to M
- { Actor A }
- { Knowledge C }
- parameters for modeling competency objectives:
  - the *number of competent resources* for each generic task <u>expected</u> at the end of the allocation horizon, O_i
  - the *performance threshold*, $thres_i$

Results

- Allocation matrix (MI)
- Total Cost

  - competency scores for each actor $r3_{i,j}$
  - the *number* of competent resources for each task <u>obtained</u> at the end of the allocation horizon, R_i

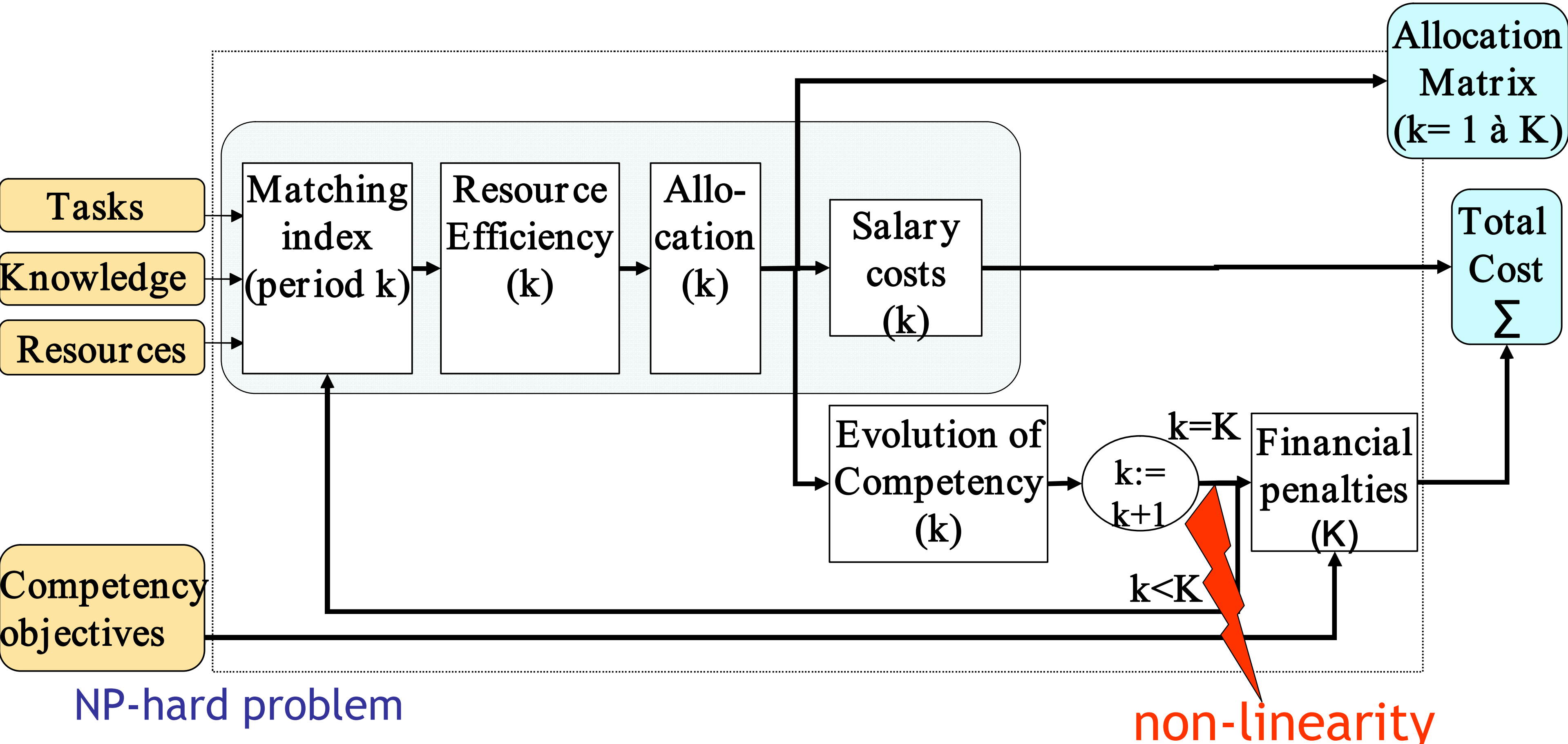
If $r3_{i,j} \geq thres_i$ ⇨ actor j is judged competent for task Ti ➔ Ri := Ri +1

$$\sum_{i=1}^{M}\varphi_i\left[\max(0, O_i - R_i)\right]$$

Task (i)	T1	T2	T3	T4
$thres_i$	0.7	0.8	0.8	0.9
O_i	3	2	4	2
R_i	2	3	3	2

Financial penalties are considered in order to take competency objectives into account.

Structure of the RH allocation problem



NP-hard problem

development of a simulated annealing algorithm

If we consider K sub-problems consecutively, we have K linear problems, easily solved by linear programming

➔ initial solution

Formulation of the optimization problem

Objective function

- Salary costs related to the activities of actors and tutors

actor — trainer — decision variables

$$\sum_{k=1}^{K}\sum_{l=1}^{P}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[(\gamma_{i,j}^{k,l}\times L_i^{k,l})\times S_j + (\gamma_{i,j}^{k,l}-1)\times L_i^{k,l}\times ST\right]\times x_{i,j}^{k,l}$$

- Financial penalties $\sum_{i=1}^{M}\varphi_i[\max(0, O_i - R_i)]$

Contraints

$$\sum_{j=1}^{N} L_i^{k,l} x_{i,j}^{k,l} = L_i^{k,l}, \forall i=1,\ldots M, \forall l=1,\ldots,P, \forall k=1,\ldots,K$$

Each task is fully assigned

$$\sum_{i=1}^{M}\sum_{l=1}^{P}\gamma_{i,j}^{k,l} L_i^{k,l} x_{i,j}^{k,l} \le LM_{j,k}, \forall j=1,\ldots N, \forall k=1,\ldots K$$

Actor's workload ≤ capacity

Prototype of competency-based HR allocation

Developed by the means of the Matlab toolbox

Data

Competency Objectives

	Nb of Competent Actors	Threshold
T1	1	0.8000
T2	2	0.7000
T3	2	0.7000
T4	2	0.8000
T5	3	0.7000
T6	4	0.7000
T7	4	0.7000
T8	3	0.8000
T9	3	0.8000
T10	1	0.8000
T11	2	0.7000
T12	3	0.8000
T13	3	0.7000
T14	4	0.8000
T15	4	0.8000

Salary Rate (Actor)

	A1	A2	A3	A4	A5	A6	A7
Rate	2000	4000	4000	4000	4000	3000	3000

Salary Rate (Tutor): 4000

Penality Rate: 2000

RUN

Competency Aspect

Competency objectives (result)

	Nb of Competent Actors
T1	1
T2	2
T3	2
T4	2
T5	5
T6	3
T7	6
T8	2
T9	3
T10	2
T11	2
T12	3
T13	3
T14	4
T15	1

Financial Aspect

Total Cost	220 947
Salary Cost	182 119
Training Cost	28 828
Financial	10 000

Allocation Matrix

Project1, Period1

	1	2	3	4
1	1....	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0

Project 2, Period 1

	1	2	3	4
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	

Project1, Period 2

	1	2	3	4
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	

Project 2, Period 2

	1	2	3	4
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	

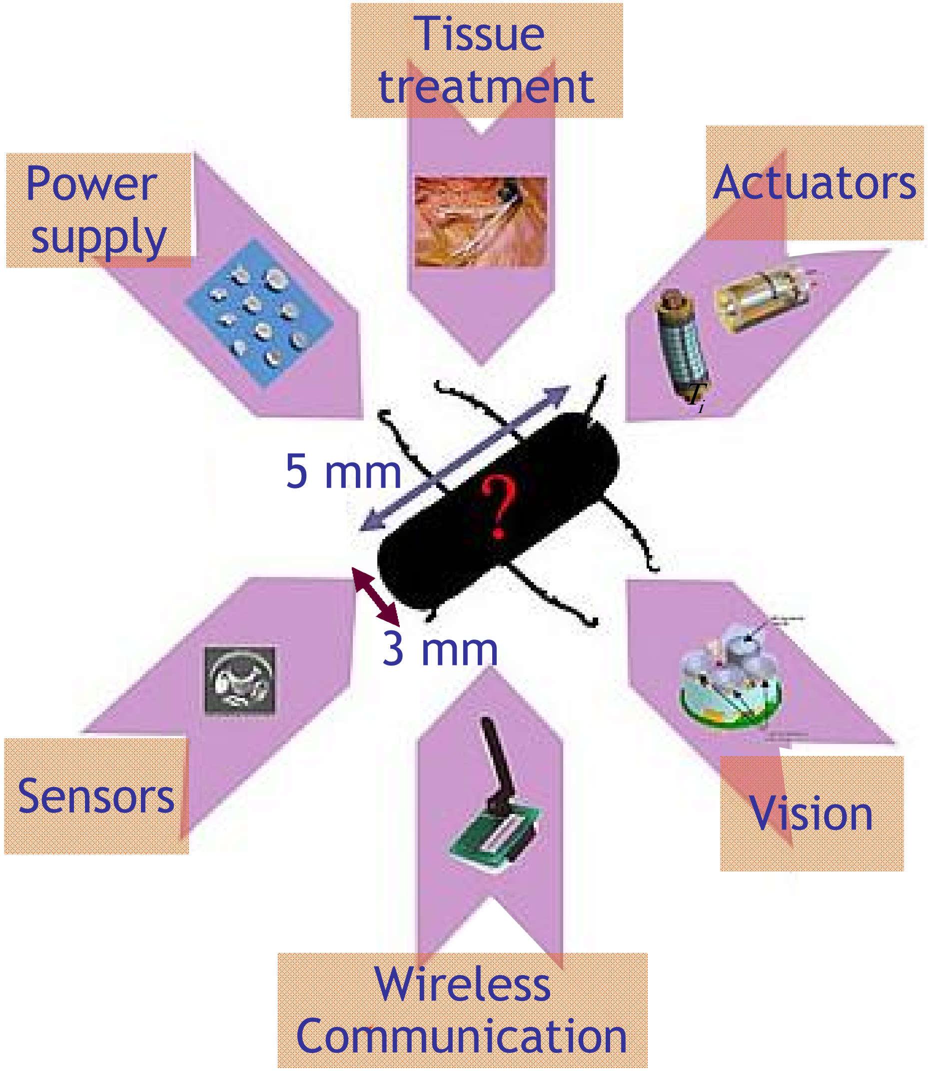
Project 1, Period 3

	1	2	3	4
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	

Project 2, Period 3

	1	2	3	4
1	0	0	0	
2	0	0	0	
3	0	0	0	
4	0	0	0	
5	0	0	0	

Case study: design of endoscopic micro-capsules



Tasks

Tasks
T1 (Define system specifications)
T2 (Design the system architecture)
T3 (Integrate the system)
T4 (Manage the project)
T5 (Design the sensor sub-system)
T6 (Design the vision sub-system)
T7 (Design the tissue treatment sub-system)
T8 (Design the locomotion sub-system)
T9 (Design the integrated circuit sub-system)
T10 (Design the control sub-system)
T11 (Design the power supply sub-system)
T12 (Design the communication sub-system)
T13 (Design the navigation-localization sub-system)
T14 (Design the nano-biotechnological sensor)
T15 (Design the micro-optics sensor)

Characterization of tasks: task-knowledge matrix (r1)

15 tasks (T), 23 knowledge (C)

automation

Signal processing

Programming

use of Matlab software

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
T1											0,4									0,2	0,6	0,4	1
T2		0,4			0,4		0,4	[illegible]			0,4		0,4		[illegible]		0,4	0,6		0,8	1	0,4	0,4
T3		0,2			0,2		0,8	[illegible]			0,6									0,8	1	0,4	
T4											0,4								0,6	0,6	0,8	1	0,2
T5							0,8	0,2			0,6			0,6							0,2	0,2	
T6								0,8	[illegible]	1					[illegible]						0,4	0,4	
T7		0,6			0,8			0,6			0,4		0,4		[illegible]						0,4	0,4	
T8		1			0,6	0,6		0,2					0,8								0,4	0,4	
T9						0,6	0,8	0,4						0,8							0,2	0,2	
T10																							
T11																							
T12																							
T13							0,2	0,6	1			0,6			0,6						0,4	0,4	
T14					0,2		0,8	0,6			0,6				0,8						0,2	0,2	
T15							0,6	0,6		1				0,8	0,6						0,2	0,2	

Achieving the task “design the navigation and localization sub-system” T13 requires good levels of knowledge in automation C8, in image and signal processing C9, in programming C12 and in Matlab software C15

Characterization of actors: actor-knowledge matrix (r2)

20 actors (A), 23 knowledge (C)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
A1											0,2									0,4	0,6	0,6	0,8
A2		0,4			0,4		0,4	0,6			0,2		0,4		0,4		0,4	0,4	0	0,4	0,8	0,6	0,4
A3		0,2					0,2	0,4			0,2		0,2		0,2				0,2	0,4	0,4	0,4	0,2
A4					0,4	0,8	1	0,2	0,6		0,4			0,4	0,4						0,4	0,6	
A5					0,4	0,6	0,8	0,6			0,4			0,8	0,6						0,4	0,6	
A6						0,6	0,6	0,4			0,4		0,4	0,6	0,4								
A7																							
A8						0,4	0,4	0,4	0,4			0,4		0,4	0,4						0,4	0,4	
A9	0,8	0,8	0,6	0,6	0,6						0,4		0,8		0,8	0,8					0,4	0,6	
A10	0,4	0,6	0,6	0,6	0,4	0,4					0,2		0,4		0,4	0,6							
A11	0,4	0,4	0,4	0,4	0,4								0,4		0,2	0,4						0,4	
A12							,8	0,8													6	0,4	
A13							,6	0,8		0,4											4	0,6	

A9, A10, A11 are mechanics engineers.

knowledge in mechanics C1-C5

software tools related to mechanics C13, C16

Different expertise profiles:

A9 : an expert ; A10 an intermediate ; A11 a novice

Interpretation of the HR allocation matrix

Allocation matrix concerning project 1

	Task	k=…	…	k=3
project 1 (p=1)	T1 (specification)	requirements a…		
	T2 (architecture)	electronic eng-… design eng-E, A19 (0,1) integrator-C, A20 (0,7)	-	-
	T3 (system integration)	-	-	integrator-C, A20
	T4 ([illegible])	…egrator-C, A20	integrator-… 0,9 …)	integrator- 0,7 0
			electronic eng-C, A6 (0,5) mechatronic eng-C, A13 (0,5)	automation eng-D, A18
	T6 (vision system)	-	automation eng-C, A16	automation eng-D, A18
	T7 (tissue treatment)	-	mechatronic eng-E, A12 (0,2) mechatronic eng-C, A14 (0,2) mechatronic eng-D, A15 (0,4) integrator-C, A20 (0,2)	mechatronic eng-C, A13 (0,2) mechatronic eng-C, A14 (0,2) mechatronic eng-D, A15 (0,4) integrator-C, A20 (0,2)
	T8 (locomotion)	-	mechatronic eng-C, A14	-
	T9 (integrated circuit)	-	electronic eng -C, A6 (0,5) electronic eng -D, A8(0,3) mechatronic eng-C, A13(0,2)	electronic eng-D, A8
	T10 (control system)	-	automation eng -C, A17	automation eng-C, A17
	T11 ([illegible])		mechatronic eng-E, A12 (0,2) mechatronic eng-C, A13 (0,8)	-
			electronic eng-D, A8	electronic eng-D, A8
	T13 (navigation)	-	electronic eng-D, A8 (0,2) automation eng-C, A16 (0,2) automation eng-C, A17 (0,6)	-
	T14 (nano sensor)	-	-	-
	T15 (optics sensor)	-	-	-

Allocation according to the required competency score

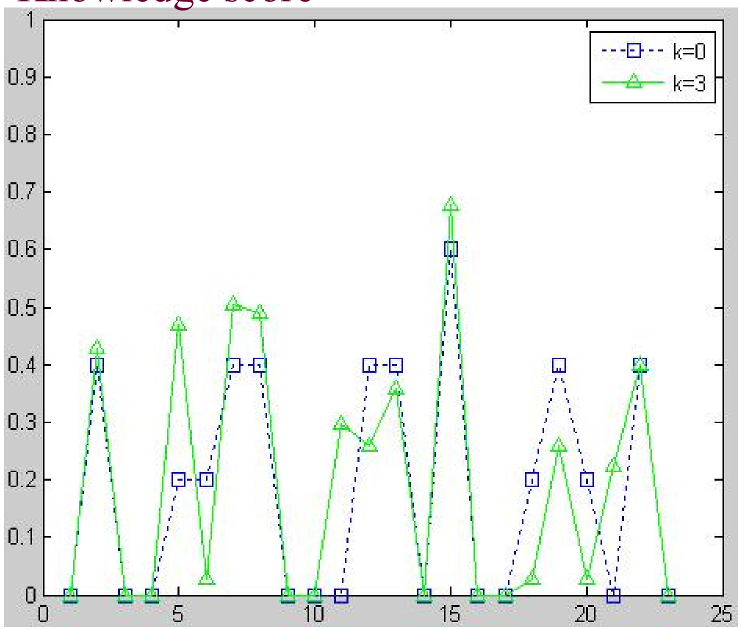
- Assigned actors
- Part of contribution

Training of novice engineers

Competency-based objective

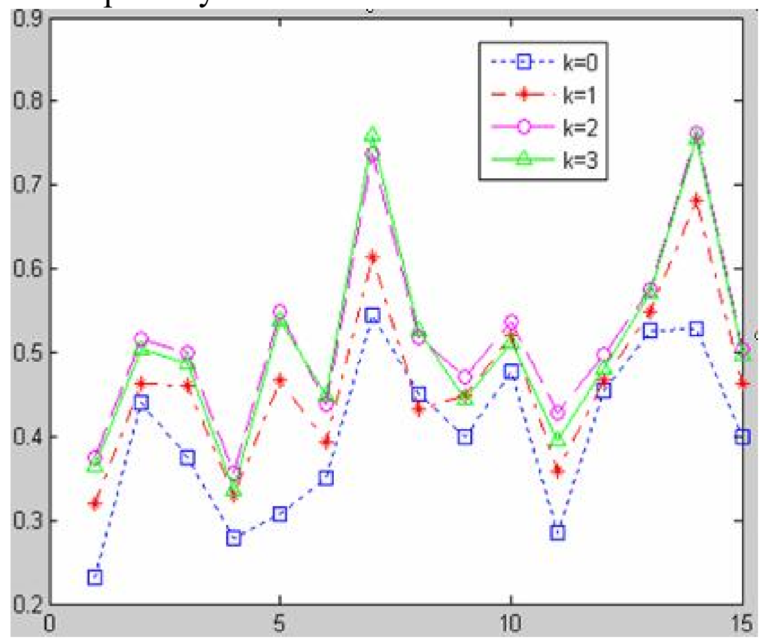
Evolutions of the knowledge scores and competency scores for actor 1

Knowledge score



(1) Knowledge c_i

Competency score



(2) Task T_i

Generic task	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	total	$\sum_{i=1}^{M}[\max(0, O_i - R_i)]$
Expected number	1	2	2	2	3	4	4	3	3	1	2	3	3	4	4		
Threshold	0,8	0,7	0,7	0,8	0,7	0,7	0,7	0,8	0,8	0,8	0,7	0,8	0,7	0,8	0,8		
Before allocation (k=1)	1	4	3	2	4	2	6	1	2	1	1	2	2	2	0	27	14
After allocation (k=K)	1	2	2	2	5	3	6	2	3	2	2	3	3	4	1	36	5

Financial Objective

Costs ($x10^3$)	LP	Greedy	Random	SA with the LP solution as an initial solution
Salary cost + Training cost	210	213	357	211
Financial penalty	18	16	20	10
Total cost	228	229	377	221
Computation time	2-3 seconds			5-6 hours

To estimate the quality of the results obtained by the proposed Simulated Annealing (SA) algorithm, we developed a greedy algorithm and a random algorithm.

- The Simulated Annealing slightly improved the Greedy algorithm (about 4%) but this decrease depends on the penalty rates concerning the non-achievement of competency objectives.
- Computation times are different but remain acceptable for SA.

Conclusion

- Formulation of an optimization model and an algorithm
- to tackle the multi-period multi-project HR allocation problem
- with goals concerning project costs and competency development
- The interest : a case study derived from micro-product development projects.

Limits

- Competency development goals are not defined completely
- Designers' knowledge and competencies may be developed out of the design projects → a need to update knowledge scores "frequently"
- global scheduling may require the maximization of HR workload (other objectives …)

Future work

- Refine the model
  - Integration of psycho-sociological capacities (collaboration efforts)
  - Integration of resource allocation / task scheduling / team formation
  - Definition of a risk probability of unsuccess associated to competency score
- Improve the optimization algorithm
  - Other meta-heuristics can be developed, tested and compared with the proposed algorithm
  - Multi-objective algorithms …
  - Sensitivity analysis, tests on larger industrial problems
- Develop software and interface with a project management tool

Thanks for your attention

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Évolution du niveau de maîtrise (r2)

Evolution du r2

Procédure (augmentation):

- Calcul de l'augmentation de r2 ou $(\Delta C_{i,l})^{k}_{c,j}$

  Pendant la période *k*, l'acteur *j* peut être alloué
  - à plusieurs tâches (indice *i*) appartenant à plusieurs projets (indice *l*).

$$(\Delta C_{i,l})^{k}_{c,j} = (r1^{k,l}_{i,c} - r2^{k-1}_{c,j})\, x^{k,l}_{i,j}$$

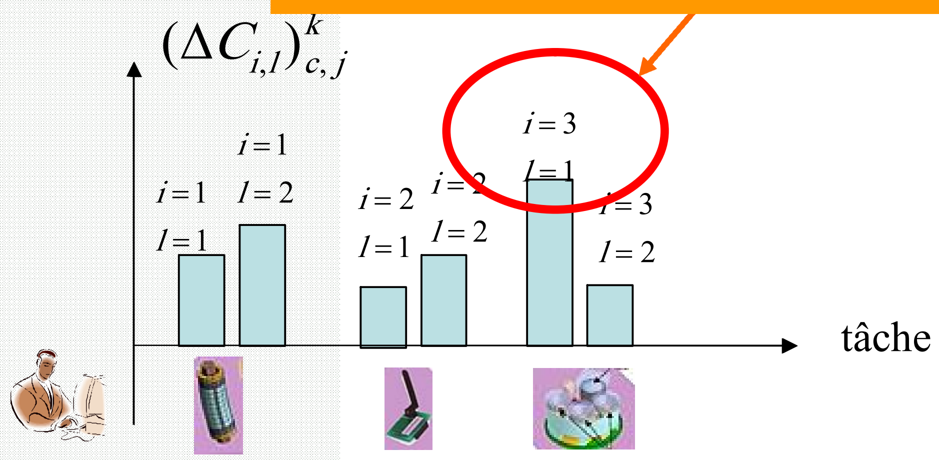
- Calcul DIF

$$DIF^{k}_{c,j} = \max_{i,l}\left[(\Delta C_{i,l})^{k}_{c,j}\right],$$

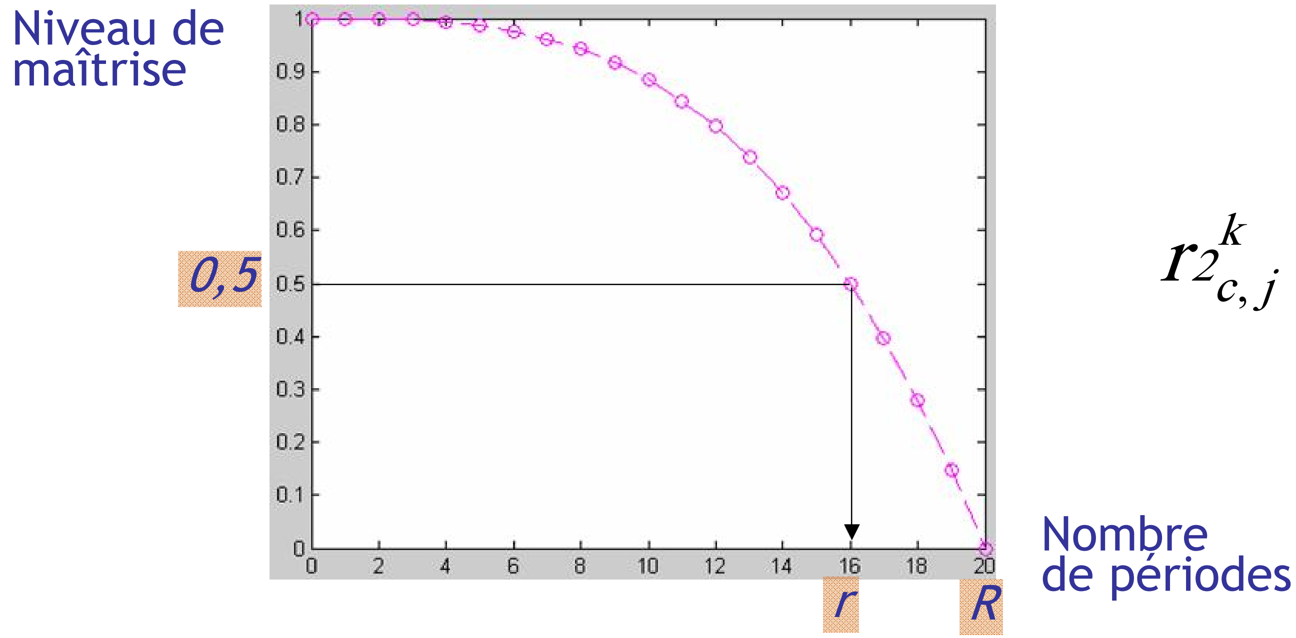
- Calcul r2

$$r2^{k}_{c,j} = r2^{k-1}_{c,j} + DIF^{k}_{c,j}$$

apprentissage le plus fort sur cette connaissance (DIF)



Evolution de compétence (r2)
Loi de régression



$$r2_{c,j}^{k} = f_{régression}(r2_{c,j}^{k-1})$$

Notre courbe de régression est inspirée par la courbe de Wright [1936]

$$y = \begin{cases} 1 - kx^{b} & , x \leq R \\ 0 & , x > R \end{cases}$$

R = le nombre de périodes non affectées où le concepteur perd tout le niveau de maîtrise dans la connaissance (y=0)

r = le nombre de périodes non affectées où le niveau de maîtrise de l'expert diminue de moitié

Etape 2: Calcul de l'évolution des compétences

Règles d'évolution des variables de compétence sur plusieurs périodes d'affectation

Période	k=1		k=2		k=3
Variables de décision d'affectation	$x_{i,j}^{1,l}$		$x_{i,j}^{2,l}$		$x_{i,j}^{3,l}$
Niveau requis de maîtrise de la connaissance	$r1_{i,\bullet}^{1,l}$		$r1_{i,\bullet}^{2,l}$		$r1_{i,\bullet}^{3,l}$
Niveau acquis de maîtrise de la connaissance	$r2_{\bullet,j}^{0}$ $+\Delta C$	$r2_{\bullet,j}^{1}$		$r2_{\bullet,j}^{2}$	$r2_{\bullet,j}^{3}$
Indicateur de similarité a priori	$V3_{i,j}^{1,l}$	$V3_{i,j}^{2,l}$		$V3_{i,j}^{3,l}$	
Indicateur de similarité a posteriori (Niveau de compétence)		$r3_{i,j}^{1}$		$r3_{i,j}^{2}$	$r3_{i,j}^{3}$

connaissance

compétence

Avant l'affectation

Après l'affectation

Niveau de maîtrise après la 1er affectation

Niveau de compétence après la 1er affectation

$$(\Delta C_{i,l})_{c,j}^{k} = (r1_{i,c}^{k,l} - r2_{c,j}^{k-1})x_{i,j}^{k,l}$$

$$V3_{i,j}^{k,l} = r1_{i,\bullet}^{k,l} \circ r2_{\bullet,j}^{k-1}$$

$$r3_{i,j}^{k} = r1_{i,\bullet} \circ r2_{\bullet,j}^{k}$$

La mise en œuvre du recuit simulé

- solution initiale
- processus de voisinage

❑ Solution initiale obtenue avec la programmation linéaire

	Période 1	Période 2	Période k
Projet 1	MI	MI	
Projet 2	MI	MI	

Coût par période

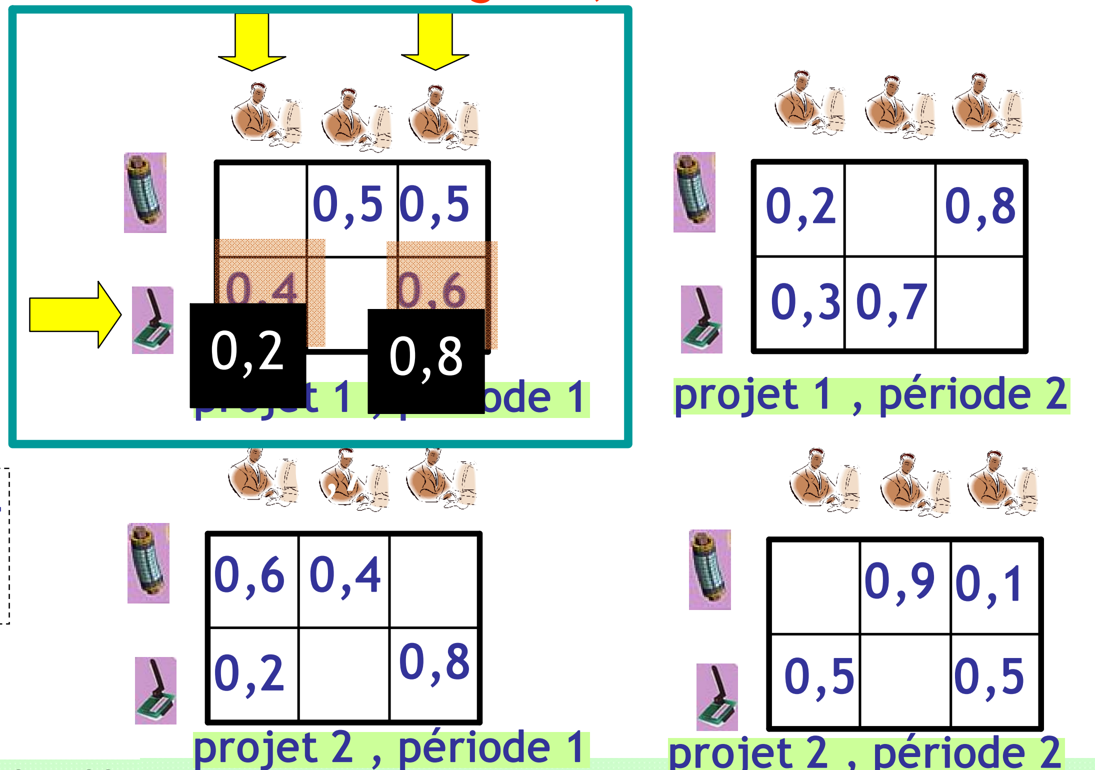
Coût Période 1	Coût Période 2	Coût total Période 1,2,…k

❑ Processus de voisinage

- Procédure d'échange

  Etape 1: sélectionner un projet/une période
  Etape 2: sélectionner une tâche
  Etape 3 : sélectionner deux acteurs selon la tâche sélectionnée

- Valeur d'échange : 0,2



	Connaissance (Maîtrise des méthodes et des outils)
C1	Acoustique, Vibration, Propagation d'ondes
C2	Mécanique, Cinématique (mécanique du mouvement)
C3	Thermodynamique, Transfert thermique, Conversion énergie
C4	Mécanique des fluides, Dynamique des fluides
C5	Matériaux
C6	Electromagnétisme
C 7	Electronique, Electrochimique
C 8	Théorie contrôle commande/ Automatique
C 9	Traitement image, Traitement signal, Télécommunication
C 10	Optique et Vision
C 11	Biomédecine (Biochimie)
C 12	Informatique
C 13	CAD, CAM
C 14	LabVIEW, SPICE
C 15	Matlab/Simulink/Dspace
C 16	Modélisation des contraintes mécaniques, Méthodes des éléments finis
C 17	Modélisation et Simulation (UML, IDEF0, SysML)
C 18	Comsol (simulation multi physique)
C 19	Optimisation, Méthodes d'aide à la décision
C 20	Sûreté fonctionnement (fiabilité, maintenabilité, sécurité)
C 21	Ingénierie système
C 22	Management de projet (qualité, délais, coût, risque)
C 23	Marketing