A RESOURCE CONSTRAINED PROJECT SCHEDULING MODEL BASED ON JOB PROFILE SCHEMES

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Abstract: The aim of the current research is to propose a Resource Constrained Project Scheduling Problem extension. Based on an employee profile derived from a job evaluation scheme and mental performance modeling, a set of new constraints and their influence on project tasks have been designed. An objective function of project makespan minimization through buffer management and human cognitive profile has been defined. Several classic prioritization rules have been reconsidered in order to offer an adapted person-centered solution rather than a process-centered one. By applying the developed model to the scheduling process, the total duration for each task has been minimized according to the employee profile. We provide an overview of the proposed model and the developed application used for obtaining computational results, along with a comparison with several commercial related tools.

Keywords: buffer management, project scheduling, prioritization rules, project makespan minimization, employee profile, intelligent systems, operations management

I. INTRODUCTION

The current research addresses the process of project scheduling from a transdisciplinary perspective, derived from three major science branches: social, behavioural and applied sciences. We define project scheduling from a software engineering resource constrained process, where resources are derived from job evaluation schemes and allocated to the project schedule, based on intellectual effort capabilities.

Problem statement and motivation

Different strategies are used nowadays to preserve the competitiveness of companies. A key role in each strategy is delivered through an efficient project management. One of the main performance criterion by project lifecycle, the minimization of project makespan(time interval between the start time of the first activity and end time of the last activity in the project's activity set), becomes a core objective [1][12]. In effective project initiation and implementation, a critical success factor is considered to be the project schedule [2][3]. Therefore, the objective of minimizing the project makespan can be achieved through a reliable schedule based on available resource allocation with budget and time constraints.

The scheduling problem addresses several research fields: project management, operations research, service system and control. [4][12]. The problem is a specific NP-hard optimization problem [4][11]. The Resource Constrained Project Scheduling (RCPS) Problem (RCPSP) is a class of scheduling problems, derived from job shop scheduling. Empirically, it describes a project through a set of available resources mapped on a set of activities, where several constraints are considered and with a defined objective function [4][10].

In project planning and scheduling, time duration estimates are used for tasks, activities and project makespan. Traditional schedules often fail, causing cost, work and time brakedowns [5][7]. To manage uncertainty, several strategies have been used. An effective strategy for industry is considered to be Buffer Management Theory (BMT) applied to both project and project activities[5]. Buffer construction is a result of using Theory of Constraints (TOC) to obtain Critical Chain Project Management (CCPM)[5][6]. Buffer management protects the project makespan in case of unexpected project changes, by taking into account the predefined constraints[5][15]. Several types of buffers can be considered: project buffer, feeding buffer, resource buffer [6][7].

Generally, the objective function for a RCPSP is to minimize costs, project makespan etc without any violation of constraints or resources [4]. As project makespan becomes a critical objective, a buffer contruction strategy can be considered to assure project schedule robustness. General resources in RCPSP are related to time, skills etc. By considering a multiple perspective on buffer construction (time, employee profile: organizational and intellectual) a robust protection is assured for project makespan.

Most of the traditional RCPSP resources are strictly enterprise related (task duration, work content, task dependencies etc), while just a few model the employee profile, but from an organizational perspective (job roles, skills, abilities, job evaluation schemes etc). Not relating

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human factors (stress, tension, fatigue etc) to the project scheduling process, obtained solutions become not person but process oriented, causing loss in accuracy.

Proposed approach

The goal of the current research is to extend the classic RCPSP by integrating a BMT perspective from a socio-behavioural point of view. A modularity approach has been considered, based on three main goals:

- development of a RCPS conceptual model (resource, constraints and objective definition), defined as WIZO (*Wise Employee-Oriented Scheduler*) conceptual model
- development of the task allocation mathematical model, defined as WIZO task allocation algorithm
- validation of the proposed full model through a desktop – based software application, defined as WIZO application

Paper outline

The current paper focuses on the WIZO model development. The introductory chapter provides the motivation of the research and defines the key concepts the research stands on. The second chapter describes the WIZO conceptual model by defining model premises, resources, constraints and the workflow of the WIZO conceptual model. A schematic description of the WIZO task allocation model is described in the third chapter. The forth chapter delivers a proof-of-concept of the WIZO model, thorough a desktop-based application used for obtaining computational results. Followed by, a comparison with a main commercial competitor is presented. In the last chapter, limitations, further model and implementation extensions are summarized.

II. THE WIZO CONCEPTUAL MODEL

The WIZO model offers an organizational perspective on the RCPSP, by mapping the BMT theory on a classical RCPSP. Related to this context, constraints and resources are derived from employees' profiles and intellectual performance.

Model premises definition

The model premises address the user environment and are based on the following assumptions:

1. IT enterprise environment: where project and team roles are defined
2. Project management methodologies: Agile Scrum with an average of 8 daily work hours
3. Employee's project commitment: where every member of the development team is working on more than one project simultaneously on the same position

Resources definition

We define the set of renewable and additive resources as the employee's profile derived from the National Joint Council Job Evaluation Scheme [8]. (Figure 1)

Cognitive skills	max L1	max L2	max L3	max L4	max L5	max L6	max L7	max L8
Knowledge	20	40	60	80	100	121	142	163
Mental skills	13	26	39	52	65	78		
Interpersonal and Communication skills	13	26	39	52	65	78		
Physical skills	13	26	39	52	65	78		
Initiative and independence	13	26	39	52	65	78	91	104
Physical demands	10	20	30	40	50			
Mental demands	10	20	30	40	50			
Emotional demands	13	26	39	52	65	78		
Responsibility for people	13	26	39	52	65	78		
Responsibility for supervision of employees	13	26	39	52	65	78		
Responsibility for financial resources	13	26	39	52	65	78		
Responsibility for physical resources	10	20	30	40	50			

Figure 1. The codified NJC Job Evaluation Scheme used as project resources[8]

The employee's profile is derived from the role assigned on a particular project and the associated abilities. Based on NJC,

- a set of 13 abilities/skills denoted as NJC factors are defined ($K = \{K_y \mid y = \overline{1, N_k}\}, N_k = 13$)
- a set of levels ($L = \{L_z \mid z = \overline{1, N_L}\}$, $N_L \in \{5,6,7,8\}$) are associated to each skill (K_y)
- a role (R_x) of the set of roles ($R = \{R_x \mid x = \overline{1, N_R}\}$) is a particular combination of all skills, each one with a particular level

$$R_x = \{L_z, K_y\} \tag{1}$$

- for each pair <skill, level>, ($< K_y, L_z >$), a predefined score is associated $S_{max}{}_{L_z}^{K_y}$

The definitions of the input data are given in relation with the NJC Scheme as follows:

- role = a combination of all the NJC abilities, each of them having one level and the specific score associate
- task/activity = a combination in a subset of the NJC abilities, each of them having one level and the specific score associated
- project = set of tasks/activities

According to the BMT, each task (J_b) of the project activities set ($J = \{J_b \mid b = \overline{1, N_J}\}$), has a predefined buffer ($T_{buffer\ offset}{}_{J_b}$), with a default duration of 50% of the task duration (T_{J_b}). Therefore, we define the initial virtual duration of a task ($T_{virtual\ offset}{}_{J_b}$) as the total duration of the task

$$T_{buffer\ offset}{}_{J_b} = 0.5\, T_{J_b}, \ b = \overline{1, N_J} \tag{2}$$

$$T_{virtual\ offset}{}_{J_b} = T_{J_b} + T_{buffer\ offset}{}_{J_b} = 1.5\, T_{J_b}, \quad b = \overline{1, N_J} \tag{3}$$

Constraints definition

Four types of constraints are derived from scores associated to the organizational skills of the employee's role and considered for each task buffer (Figure 2).

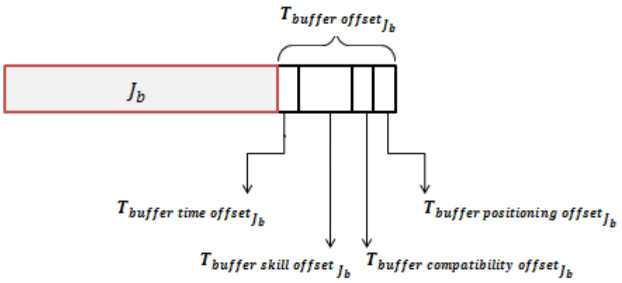

Figure 2. Task Initial Buffer Structure

- Time constraint - defines the influence of the task duration over the task buffer
- Skill constraint - defines the influence of the skill level over the task buffer
- Compatibility constraint - defines the influence of the compatibility between consecutive tasks, over the task buffer
- Positioning constraint - defines the influence of the task positioning in the project duration, over the task buffer

The influence that each type of constraint has on the initial task buffer is quantified through weights:

$$T_{buffer\ time\ offset\ J_b} = \alpha T_{buffer\ offset\ J_b} \quad (4)$$
$$T_{buffer\ skill\ offset\ J_b} = \beta T_{buffer\ offset\ J_b}$$
$$T_{buffer\ compatibility\ offset\ J_b} = \gamma T_{buffer\ offset\ J_b}$$
$$T_{buffer\ positioning\ offset\ J_b} = \theta T_{buffer\ offset\ J_b}$$

Where,

$$\alpha + \beta + \gamma + \theta = 1; \quad (5)$$

represent the proportions in which the four contraints are initially combined

Problem definition

A classical definition for a RCPSP consists of problem formulation and solution modeling [9]. The problem formulation is based on defining the input variables: activity set, resources and constraints [12]. Project activities for which resource have a given availability, are interrelated by precedence and resource constraints. [9] Solution modeling consists of defining the objective function for resource allocation based on the given constraints. Several reasons can be emphasized accordingly to which, project makespan minimization is considered to be one of the most proper objective [9][10].

For the WIZO model, the RCPSP is defined for multiple projects and can be outlined as follows. Given a set of projects, $\left(P = \{P_q \mid q = \overline{1, N_m}\}\right.$, where N_m represents the number of concurrent projects with a total duration (T_P), the goal is to map the cumulated sets of activies $\{J_{P_q}\}$ in the associated time interval, based on the a prioritization algorithm and constraints definition, with an objective function of duration minimization. Duration minimization is achieved through each project makespan minimization through daily work duration minimization by task duration reduction.

The virtual duration of each task is minimized $(T_{virtual\ J_b} < T_{virtual\ offset\ J_b})$ through buffer minimization $(T_{buffer\ J_b} < T_{buffer\ offset\ J_b})$.

$$T_{buffer\ J_b} = T_{buffer\ time\ J_b} + T_{buffer\ skill\ J_b} + T_{buffer\ compatibility\ J_b} + T_{buffer\ positioning\ J_b} \quad (6)$$

Where,

$T_{buffer\ time\ J_b} < T_{buffer\ time\ offset\ J_b}$
$T_{buffer\ skill\ J_b} < T_{buffer\ skill\ offset\ J_b}$
$T_{buffer\ compatibility\ J_b} < T_{buffer\ compatibility\ offset\ J_b}$
$T_{buffer\ positioning\ J_b} < T_{buffer\ positioning\ offset\ J_b}$

WIZO model workflow

The WIZO conceptual model is represented in Figure 3.

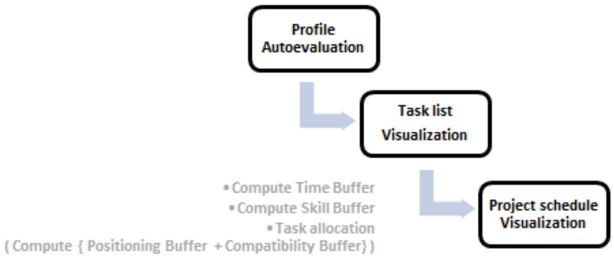

Figure 3. Conceptual diagram of the WIZO model

- For the Profile Evaluation phase, the employee autorates (min0…max5) his organizational profile, described accordingly to the National Joint Council Job Evaluation Scheme (Figure 1), where each role is characterized by a number of 13 skills with different ability levels [1..7]. For each pair <skill, level> a predefined scored is associated. Therefore, the profile is computed as a cumulated number from skill scores.
- The Task Visualization Phase offers the employee a summary of the tasks assigned for the set of concurrent projects he is working on
- The Task Allocation algorithm operates a buffer adjustment based on task positioning by day, and by compatibility between tasks in a day

III. THE WIZO TASK ALLOCATION ALGORITHM

The WIZO task allocation algorithm offers an organizational approach by adapting the RCPS prioritization rules such as Serial Scheduling Generation Scheme (SSGS)[9][10][14] and Maximum Total Work Content (MAXTWK)[13][14][20] to the employee cognitive needs, as follows:

- SSGS reinterpretation: the task allocation process is executed in a number of phases equal to the number of the multi-project tasks $(\{J_{P_q}\})$; for each task positioning in the task array the best compatibility with the neighborhood tasks is chosen, where neighborhood tasks are defined as tasks committed by the employee in the same day

- MAXTWK reinterpretation: the activity with the highest priority is considered to be the highest complex activity, where the complexity is given by the proportion between the task duration (T_{J_b}) and the computed task buffer.

Particularly, the WIZO task allocation algorithm consists of three development phases: depth, horizontal and vertical

Depth allocation

For each task, a complexity calculation has been performed. Task complexity has been defined as the ratio between and buffer duration. Therefore, the most complex activity is considered to be the one with the highest value of the complexity ratio

Horizontal allocation

For each day of the week we define a priority by applying the Maxwell's Performance Curve (Figure 4) on the multi-project total duration. The task with the highest complexity will be positioned in the most prior day, following a reinterpretation of the MAXTWK prioritization rule.

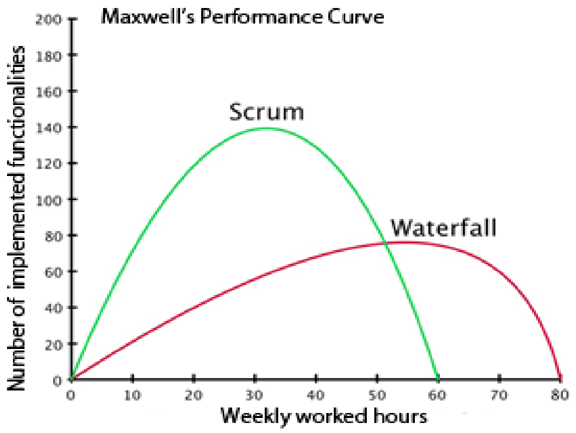

Figure 4. Maxwell's comparison between SCRUM and Waterfall Productivity [21]

Maxwell's curve assumes that the productivity of employee's work decreases by an inverted U law applied on the total number of worked hours/ week. Based on SCRUM definition, a task should not exceed more than 16 hours.

Vertical allocation

Based on the employee's role a day complexity is computed. A maximum complexity level is defined for each day as the maximum level of skills, the employee can use in that particular day. A complexity coefficient has been also derived from the Adapted Human Intellectual Performance[16][17] (Figure 5)

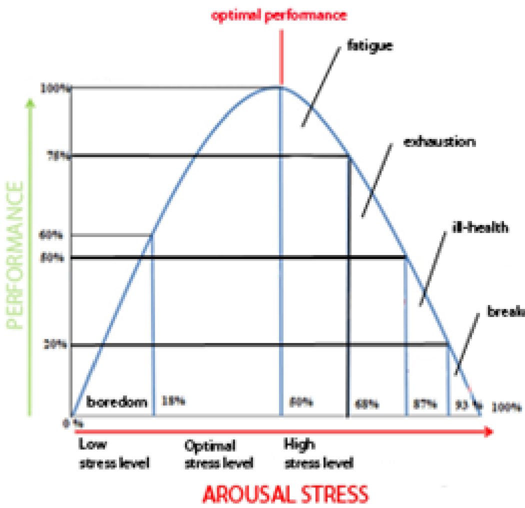

Figure 5. Adapted Human Intellectual Performance Curve [17]

Nixon's stress curve denotes that the level of intellectual performance is reduced with stress arousal, while an optimum stress zone can be defined approximately half-way of the maximum level of stress.

The maximum complexity corresponds to an 8h task that uses all the skills in the employee profile with maximum scores. For vertical allocation, tasks have to be distributed in such a way for which the computed complexity does not exceed the maximum defined complexity. If the cumulated task durations exceed the total number of accepted working hours (8h), for the last task in the day a trunking operation is performed. The trunked task will be scheduled as the first task in the following day (SSGS prioritization rule interpretation). Therefore, finding the optimum combination of tasks for each day, becomes the vertical allocation's objective

IV.COMPUTATIONAL RESULTS

For model validation, a software application has been designed. Accordingly to the WIZO conceptual model, the WIZO application targets employees in the software engineering industry, specifically development teams.

Three views have been considered: Employee Self-Evaluation (Figure 6), Assigned Tasks (Figure 7), Scheduled Tasks (Figure 8)

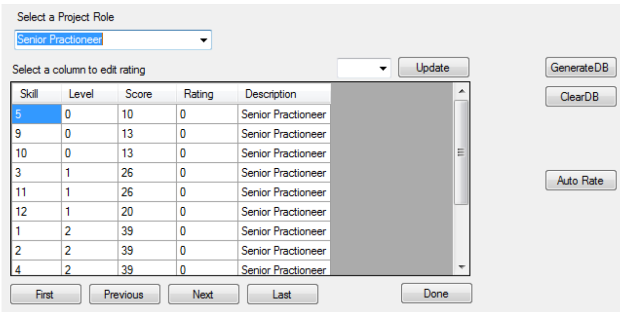

Figure 6. "Employee Self-Evaluation" view

Several employee roles have been considered, according to an adapted NJC Job Evaluation Scheme: *Senior Practioneer,Service Manager, Practice Manager, Team Manager*. After role selection, the associated skills and the total computed score are being filled in and the employee evaluates each of his abilities through rating. An individual score is computed for the employee, in which the score for each level is adjusted based on the auto rating. (For the current Proof-Of-Concept, an auto-rating function has been provided)

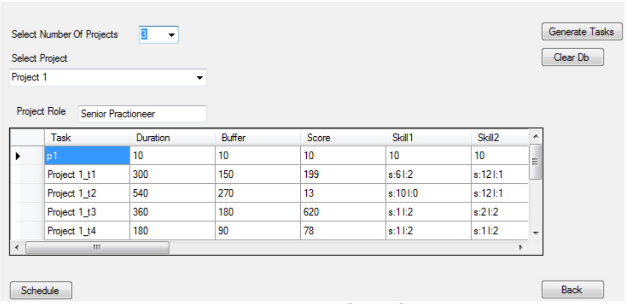

Figure 7. "Assigned Tasks" view

For the selected role, the employee chooses the number of concurrent projects he is being assigned to. For each project, the list of the employee's tasks is displayed. Task definition is displayed for each item (associated skills and levels, total score). The employee can perform a task if the individual score for each skill is greater than the score of the same skill part of the task definition.

Offset task buffer is computed (2) and displayed for each task item in the list. (For the current proof-of-concept a task generation function has been provided to avoid skill compatibility issues between employee skills and task skills)

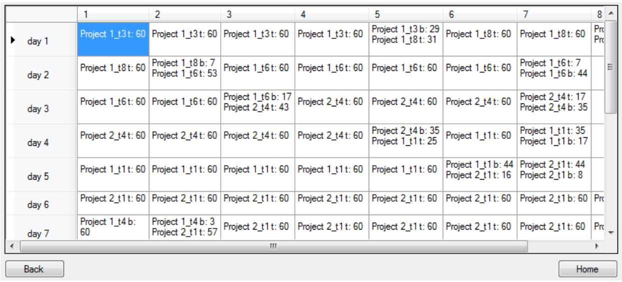

Figure 8. "Scheduled Tasks" view

After buffer computation and allocation algorithm are performed, the scheduled activities are displayed per day/per hours. Tasks are being distributed over the cumulated multi-project duration based on the initial premises and constraints. For each task, task duration T_{J_b} and task buffer duration are provided $T_{buffer\ J_b}$

Buffer Minimization

Given an example for a 'Team Leader', we have designed 3 task lists for 3 concurrent projects:

Task list for Project 1		
Task 1 duration: 420 skills needed: skill: 11 level: 1 skill: 3 level: 1 skill: 5 level: 0 skill: 9 level: 1 skill: 4 level: 4 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 1 level: 4	Task 2 duration: 540 skills needed: skill: 4 level: 4 skill: 5 level: 0 skill: 5 level: 0 skill: 9 level: 1 skill: 4 level: 4 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 1 level: 4	Task 3 duration: 420 skills needed: skill: 0 level: 6 skill: 9 level: 1 skill: 0 level: 6 skill: 12 level: 1 skill: 4 level: 4 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 1 level: 4
Task 4 duration: 180 skills needed: skill: 9 level: 1 skill: 7 level: 2 skill: 0 level: 6 skill: 12 level: 1 skill: 4 level: 4 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 1 level: 4	Task 5 duration: 240 skills needed: skill: 9 level: 1 skill: 9 level: 1 skill: 8 level: 4 skill: 12 level: 1 skill: 10 level: 0 skill: 12 level: 1 skill: 11 level: 1 skill: 9 level: 1 skill: 10 level: 0	Task 6 duration: 60 skills needed: skill: 2 level: 4 skill: 10 level: 0 skill: 12 level: 1 skill: 12 level: 1 skill: 10 level: 0 skill: 12 level: 1 skill: 11 level: 1 skill: 9 level: 1 skill: 10 level: 0
Task 7 duration: 480 skills needed: skill: 0 level: 6 skill: 6 level: 3 skill: 5 level: 0 skill: 6 level: 3 skill: 0 level: 6 skill: 9 level: 1 skill: 11 level: 1 skill: 9 level: 1 skill: 10 level: 0	Task 8 duration: 60 skills needed: skill: 9 level: 1 skill: 5 level: 0 skill: 12 level: 1 skill: 3 level: 1 skill: 2 level: 4 skill: 6 level: 3 skill: 11 level: 1 skill: 9 level: 1 skill: 10 level: 0	

Table 1. Task list for Project 1

Task list for Project 2		
Task 1 duration: 240 skills needed: skill: 7 level: 2 skill: 12 level: 1 skill: 8 level: 4 skill: 11 level: 1 skill: 3 level: 1 skill: 11 level: 1 skill: 9 level: 1	Task 2 duration: 420 skills needed: skill: 4 level: 4 skill: 3 level: 1 skill: 3 level: 1 skill: 8 level: 4 skill: 12 level: 1 skill: 3 level: 1 skill: 7 level: 2 skill: 7 level: 2	Task 3 duration: 420 skills needed: skill: 6 level: 3 skill: 6 level: 3 skill: 5 level: 0 skill: 9 level: 1 skill: 9 level: 1 skill: 12 level: 1 skill: 6 level: 3 skill: 7 level: 2
Task 4 duration: 300 skills needed: skill: 12 level: 1 skill: 4 level: 4 skill: 5 level: 0 skill: 0 level: 6 skill: 3 level: 1 skill: 12 level: 1 skill: 6 level: 3 skill: 11 level: 1 skill: 8 level: 4 skill: 8 level: 4 skill: 9 level: 1	Task 5 duration: 420 skills needed: skill: 1 level: 4 skill: 12 level: 1 skill: 8 level: 4 skill: 8 level: 4 skill: 3 level: 1 skill: 12 level: 1 skill: 6 level: 3 skill: 11 level: 1 skill: 8 level: 4 skill: 8 level: 4 skill: 9 level: 1	Task 6 duration: 420 skills needed: skill: 1 level: 4 skill: 0 level: 6 skill: 1 level: 4 skill: 6 level: 3 skill: 11 level: 1 skill: 6 level: 3 skill: 3 level: 1 skill: 8 level: 4 skill: 8 level: 4 skill: 7 level: 2 skill: 2 level: 4 skill: 6 level: 3 skill: 0 level: 6
Task 7 duration: 180 skills needed: skill: 10 level: 0 skill: 0 level: 6 skill: 4 level: 4 skill: 6 level: 3 skill: 11 level: 1 skill: 6 level: 3 skill: 3 level: 1 skill: 8 level: 4 skill: 8 level: 4 skill: 7 level: 2 skill: 2 level: 4 skill: 6 level: 3 skill: 0 level: 6		

Table 2. Task list for Project 2

Task list for Project 3

Task 1 duration: 240 skills needed: skill: 7 level: 2 skill: 12 level: 1 skill: 8 level: 4 skill: 11 level: 1 skill: 3 level: 1 skill: 11 level: 1 skill: 9 level: 1	Task 2 duration: 180 skills needed: skill: 12 level: 1 skill: 2 level: 4 skill: 7 level: 2 skill: 4 level: 4 skill: 8 level: 4 skill: 6 level: 3 skill: 1 level: 4	Task 3 duration: 240 skills needed: skill: 11 level: 1 skill: 7 level: 2 skill: 10 level: 0 skill: 8 level: 4 skill: 3 level: 1 skill: 3 level: 1 skill: 1 level: 4
Task 4 duration: 240 skills needed: skill: 0 level: 6 skill: 0 level: 6 skill: 0 level: 6 skill: 6 level: 3 skill: 11 level: 1 skill: 4 level: 4 skill: 5 level: 0 skill: 8 level: 4	Task 5 duration: 360 skills needed: skill: 6 level: 3 skill: 0 level: 6 skill: 0 level: 6 skill: 6 level: 3 skill: 11 level: 1 skill: 4 level: 4 skill: 5 level: 0 skill: 8 level: 4	Task 6 duration: 120 skills needed: skill: 12 level: 1 skill: 5 level: 0 skill: 1 level: 4 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 4 level: 4 skill: 4 level: 4
Task 7 duration: 540 skills needed: skill: 2 level: 4 skill: 4 level: 4 skill: 11 level: 1 skill: 6 level: 3 skill: 8 level: 4 skill: 11 level: 1 skill: 4 level: 4 skill: 4 level: 4	Task 8 duration: 180 skills needed: skill: 1 level: 4 skill: 7 level: 2 skill: 11 level: 1 skill: 9 level: 1 skill: 3 level: 1 skill: 12 level: 1 skill: 4 level: 4 skill: 4 level: 4	Task 9 duration: 180 skills needed: skill: 3 level: 1 skill: 1 level: 4 skill: 3 level: 1 skill: 8 level: 4 skill: 5 level: 0 skill: 6 level: 3 skill: 4 level: 4 skill: 4 level: 4

Table 3. Task list for Project 3

days needed to complete all the tasks: 20

Intermediate results have been obtained based on applying time and skill buffer computation:

```
################# Adjust Buffer Based On Time #################
Task: Project 1_t1 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 1_t2 duration= 9 Initial buffer: 4.5 After reduction: 4.32 Reduction amount: 0.1799998
Task: Project 1_t3 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 1_t4 duration= 3 Initial buffer: 1.5 After reduction: 1.275 Reduction amount: 0.225
Task: Project 1_t5 duration= 4 Initial buffer: 2 After reduction: 1.7 Reduction amount: 0.3
Task: Project 1_t6 duration= 1 Initial buffer: 0.5 After reduction: 0.44 Reduction amount: 0.06000001
Task: Project 1_t7 duration= 8 Initial buffer: 4 After reduction: 3.6 Reduction amount: 0.4
Task: Project 1_t8 duration= 1 Initial buffer: 0.5 After reduction: 0.44 Reduction amount: 0.06000001
Task: Project 2_t1 duration= 4 Initial buffer: 2 After reduction: 1.7 Reduction amount: 0.3
Task: Project 2_t2 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 2_t3 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 2_t4 duration= 5 Initial buffer: 2.5 After reduction: 2.125 Reduction amount: 0.375
Task: Project 2_t5 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 2_t6 duration= 7 Initial buffer: 3.5 After reduction: 3.15 Reduction amount: 0.35
Task: Project 2_t7 duration= 3 Initial buffer: 1.5 After reduction: 1.275 Reduction amount: 0.225
Task: Project 3_t1 duration= 6 Initial buffer: 3 After reduction: 2.7 Reduction amount: 0.3
Task: Project 3_t2 duration= 3 Initial buffer: 1.5 After reduction: 1.275 Reduction amount: 0.225
Task: Project 3_t3 duration= 4 Initial buffer: 2 After reduction: 1.7 Reduction amount: 0.3
Task: Project 3_t4 duration= 4 Initial buffer: 2 After reduction: 1.7 Reduction amount: 0.3
Task: Project 3_t5 duration= 6 Initial buffer: 3 After reduction: 2.7 Reduction amount: 0.3
Task: Project 3_t6 duration= 2 Initial buffer: 1 After reduction: 0.88 Reduction amount: 0.12
Task: Project 3_t7 duration= 9 Initial buffer: 4.5 After reduction: 4.32 Reduction amount: 0.1799998
Task: Project 3_t8 duration= 3 Initial buffer: 1.5 After reduction: 1.275 Reduction amount: 0.225
Task: Project 3_t9 duration= 3 Initial buffer: 1.5 After reduction: 1.275 Reduction amount: 0.225

################# Adjust Buffer Based On Skills #################
Task: Project 1_t1 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 1_t2 Initial buffer: 4.5 After reduction: 2.7 Reduction Amount 1.8
Task: Project 1_t3 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 1_t4 Initial buffer: 1.5 After reduction: 0.9 Reduction Amount 0.6
Task: Project 1_t5 Initial buffer: 2 After reduction: 1.2 Reduction Amount 0.8
Task: Project 1_t6 Initial buffer: 0.5 After reduction: 0.3 Reduction Amount 0.2
Task: Project 1_t7 Initial buffer: 4 After reduction: 2.4 Reduction Amount 1.6
Task: Project 1_t8 Initial buffer: 0.5 After reduction: 0.3 Reduction Amount 0.2
Task: Project 2_t1 Initial buffer: 2 After reduction: 1.2 Reduction Amount 0.8
Task: Project 2_t2 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 2_t3 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 2_t4 Initial buffer: 2.5 After reduction: 1.5 Reduction Amount 1
Task: Project 2_t5 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 2_t6 Initial buffer: 3.5 After reduction: 2.1 Reduction Amount 1.4
Task: Project 2_t7 Initial buffer: 1.5 After reduction: 0.9 Reduction Amount 0.6
Task: Project 3_t1 Initial buffer: 3 After reduction: 1.8 Reduction Amount 1.2
Task: Project 3_t2 Initial buffer: 1.5 After reduction: 0.9 Reduction Amount 0.6
Task: Project 3_t3 Initial buffer: 2 After reduction: 1.2 Reduction Amount 0.8
Task: Project 3_t4 Initial buffer: 2 After reduction: 1.2 Reduction Amount 0.8
Task: Project 3_t5 Initial buffer: 3 After reduction: 1.8 Reduction Amount 1.2
Task: Project 3_t6 Initial buffer: 1 After reduction: 0.6 Reduction Amount 0.4
Task: Project 3_t7 Initial buffer: 4.5 After reduction: 2.7 Reduction Amount 1.8
Task: Project 3_t8 Initial buffer: 1.5 After reduction: 0.9 Reduction Amount 0.6
Task: Project 3_t9 Initial buffer: 1.5 After reduction: 0.9 Reduction Amount 0.6
```

Therefore, after applying both type analysis each task buffer has been reduced as follows:

```
################# Task Duration #################
Task: Project 1_t1 has duration of 7 and buffer: 1.75
Task: Project 1_t2 has duration of 9 and buffer: 2.52
Task: Project 1_t3 has duration of 7 and buffer: 1.75
Task: Project 1_t4 has duration of 3 and buffer: 0.675
Task: Project 1_t5 has duration of 4 and buffer: 0.9
Task: Project 1_t6 has duration of 1 and buffer: 0.24
Task: Project 1_t7 has duration of 8 and buffer: 2
Task: Project 1_t8 has duration of 1 and buffer: 0.24
Task: Project 2_t1 has duration of 4 and buffer: 0.9
Task: Project 2_t2 has duration of 7 and buffer: 1.75
Task: Project 2_t3 has duration of 7 and buffer: 1.75
Task: Project 2_t4 has duration of 5 and buffer: 1.125
Task: Project 2_t5 has duration of 7 and buffer: 1.75
Task: Project 2_t6 has duration of 7 and buffer: 1.75
Task: Project 2_t7 has duration of 3 and buffer: 0.675
Task: Project 3_t1 has duration of 6 and buffer: 1.5
Task: Project 3_t2 has duration of 3 and buffer: 0.675
Task: Project 3_t3 has duration of 4 and buffer: 0.9
Task: Project 3_t4 has duration of 4 and buffer: 0.9
Task: Project 3_t5 has duration of 6 and buffer: 1.5
Task: Project 3_t6 has duration of 2 and buffer: 0.48
Task: Project 3_t7 has duration of 9 and buffer: 2.52
Task: Project 3_t8 has duration of 3 and buffer: 0.675
Task: Project 3_t9 has duration of 3 and buffer: 0.675
```

According to the task allocation alogorithm, buffer reduction based on day positioning (horizontal allocation) is then applied:

```
################# Show results based only on day buffer reduction #################

################### Day 1 #################

task: Project 1_t4 Nr. hours: 3 Buffer: 22.5
task: Project 2_t2 Nr. hours: 4 Buffer: 35.99999

################### Day 2 #################
task: Project 2_t2 Nr. hours: 3 Buffer: 27
task: Project 1_t1 Nr. hours: 3 Buffer: 27

################### Day 3 #################
task: Project 1_t1 Nr. hours: 4 Buffer: 36
task: Project 1_t3 Nr. hours: 2 Buffer: 18

################### Day 4 #################
task: Project 1_t3 Nr. hours: 5 Buffer: 45
task: Project 3_t9 Nr. hours: 2 Buffer: 15

################### Day 5 #################
task: Project 3_t9 Nr. hours: 1 Buffer: 7.5
task: Project 1_t8 Nr. hours: 1 Buffer: 8.4
task: Project 3_t1 Nr. hours: 4 Buffer: 35.99999

################### Day 6 #################
task: Project 3_t1 Nr. hours: 2 Buffer: 18
task: Project 2_t4 Nr. hours: 5 Buffer: 37.5

################### Day 7 #################
task: Project 1_t5 Nr. hours: 4 Buffer: 30
task: Project 3_t2 Nr. hours: 3 Buffer: 22.5

################### Day 8 #################
task: Project 2_t1 Nr. hours: 4 Buffer: 30
task: Project 1_t2 Nr. hours: 2 Buffer: 21.60001

################### Day 9 #################
task: Project 1_t2 Nr. hours: 6 Buffer: 73.80002

################### Day 10 #################
task: Project 1_t2 Nr. hours: 3 Buffer: 28.7
task: Project 1_t7 Nr. hours: 3 Buffer: 31.49999

################### Day 11 #################
task: Project 1_t7 Nr. hours: 5 Buffer: 52.5
task: Project 3_t3 Nr. hours: 1 Buffer: 8.999998

################### Day 12 #################
task: Project 3_t3 Nr. hours: 3 Buffer: 29.7
task: Project 2_t5 Nr. hours: 3 Buffer: 34.19999

################### Day 13 #################
task: Project 2_t5 Nr. hours: 4 Buffer: 45.6
task: Project 3_t6 Nr. hours: 2 Buffer: 21.6

################### Day 14 #################
task: Project 2_t7 Nr. hours: 3 Buffer: 29.7
task: Project 3_t5 Nr. hours: 3 Buffer: 34.20001

################### Day 15 #################
task: Project 3_t5 Nr. hours: 3 Buffer: 36
task: Project 3_t8 Nr. hours: 3 Buffer: 31.5

################### Day 16 #################
task: Project 3_t4 Nr. hours: 4 Buffer: 42
task: Project 2_t3 Nr. hours: 2 Buffer: 24.00001

################### Day 17 #################
task: Project 2_t3 Nr. hours: 5 Buffer: 60
task: Project 1_t6 Nr. hours: 1 Buffer: 11.4
```

```
#################### Day 18 #################
task: Project 2_t6 Nr. hours: 6 Buffer: 72.00002

#################### Day 19 #################
task: Project 2_t6 Nr. hours: 1 Buffer: 12
task: Project 3_t7 Nr. hours: 5 Buffer: 69.00001

#################### Day 20 #################
task: Project 3_t7 Nr. hours: 4 Buffer: 62.40001
```

Simultaneously, the second phase of the allocation algorithm, buffer reduction based on task compatibility (vertical and depth allocation) is applied:

```
#################  Show results after apply compatibility buffer reduction
#################

#################### Day 1 #################
task: Project 1_t4 Nr. hours: 3 Buffer: 22.20107
task: Project 2_t2 Nr. hours: 4 Buffer: 35.70106

#################### Day 2 #################
task: Project 2_t2 Nr. hours: 3 Buffer: 26.70107
task: Project 1_t1 Nr. hours: 3 Buffer: 26.60142

#################### Day 3 #################
task: Project 1_t1 Nr. hours: 4 Buffer: 35.60453
task: Project 1_t3 Nr. hours: 2 Buffer: 17.50566

#################### Day 4 #################
task: Project 1_t3 Nr. hours: 5 Buffer: 44.50178
task: Project 3_t9 Nr. hours: 2 Buffer: 14.90036

#################### Day 5 #################
task: Project 3_t9 Nr. hours: 1 Buffer: 7.429245
task: Project 1_t8 Nr. hours: 1 Buffer: 8.329244
task: Project 3_t1 Nr. hours: 4 Buffer: 35.85848

#################### Day 6 #################
task: Project 3_t1 Nr. hours: 2 Buffer: 17.80071
task: Project 2_t4 Nr. hours: 5 Buffer: 37.00178

#################### Day 7 #################
task: Project 1_t5 Nr. hours: 4 Buffer: 29.60471
task: Project 3_t2 Nr. hours: 3 Buffer: 22.20353

#################### Day 8 #################
task: Project 2_t1 Nr. hours: 4 Buffer: 29.61271
task: Project 1_t2 Nr. hours: 2 Buffer: 21.37409

#################### Day 9 #################
task: Project 1_t2 Nr. hours: 6 Buffer: 73.62798

#################### Day 10 #################
task: Project 1_t2 Nr. hours: 3 Buffer: 28.46931
task: Project 1_t7 Nr. hours: 3 Buffer: 31.00566

#################### Day 11 #################
task: Project 1_t7 Nr. hours: 5 Buffer: 52.00411
task: Project 3_t3 Nr. hours: 1 Buffer: 8.702465

#################### Day 12 #################
task: Project 3_t3 Nr. hours: 3 Buffer: 29.4026
task: Project 2_t5 Nr. hours: 3 Buffer: 33.80346

#################### Day 13 #################
task: Project 2_t5 Nr. hours: 4 Buffer: 45.21049
task: Project 3_t6 Nr. hours: 2 Buffer: 21.40524

#################### Day 14 #################
task: Project 2_t7 Nr. hours: 3 Buffer: 29.4158
task: Project 3_t5 Nr. hours: 3 Buffer: 33.91581

#################### Day 15 #################
task: Project 3_t5 Nr. hours: 3 Buffer: 35.70353
task: Project 3_t8 Nr. hours: 3 Buffer: 31.20353

#################### Day 16 #################
task: Project 3_t4 Nr. hours: 4 Buffer: 41.61271
task: Project 2_t3 Nr. hours: 2 Buffer: 23.51589

#################### Day 17 #################
task: Project 2_t3 Nr. hours: 5 Buffer: 59.50178
task: Project 1_t6 Nr. hours: 1 Buffer: 11.30035

#################### Day 18 #################
task: Project 2_t6 Nr. hours: 6 Buffer: 71.90833

#################### Day 19 #################
task: Project 2_t6 Nr. hours: 1 Buffer: 11.9146
task: Project 3_t7 Nr. hours: 5 Buffer: 68.65841

#################### Day 20 #################
task: Project 3_t7 Nr. hours: 4 Buffer: 62.12303
```

Therefore, applying the WIZO model on the initial set of tasks, the following final results have been obtained (Table 4, Table 5, Table- 6):

Task list for Project 1	
$T_{J_1^{P1}} = 420$	$T_{J_2^{P1}} = 540$
$T_{buffer\ offset\ J_1^{P1}}$ =210	$T_{buffer\ offset\ J_2^{P1}}$ =270
$T_{buffer\ J_1^{P1}}$ =62.20595	$T_{buffer\ J_2^{P1}}$ =123.47138
Buffer minimization of: 70.37%	Buffer minimization of: 54.27%
$T_{J_3^{P1}}$ =420	$T_{J_4^{P1}}$ =180
$T_{buffer\ offset\ J_3^{P1}}$ =210	$T_{buffer\ offset\ J_4^{P1}}$ =90
$T_{buffer\ J_3^{P1}}$ =62.00744	$T_{buffer\ J_4^{P1}}$ =22.20107
Buffer minimization of: 70.47%	Buffer minimization of: 75.33%
$T_{J_5^{P1}}$ =240	$T_{J_6^{P1}}$ =60
$T_{buffer\ offset\ J_5^{P1}}$ =120	$T_{buffer\ offset\ J_6^{P1}}$ =30
$T_{buffer\ J_5^{P1}}$ =29.60471	$T_{buffer\ J_6^{P1}}$ =11.30035
Buffer minimization of: 75.33%	Buffer minimization of: 62.33%
$T_{J_7^{P1}}$ =480	$T_{J_8^{P1}}$ =60
$T_{buffer\ offset\ J_1^{P1}}$ =240	$T_{buffer\ offset\ J_1^{P1}}$ =30
$T_{buffer\ J_7^{P1}}$ =83.00977	$T_{buffer\ J_8^{P1}}$ =8.329244
Buffer minimization of: 65.41%	Buffer minimization of: 72.23%

Table 4. Buffer minimization for the Task Set in Project 1

Task list for Project 2	
$T_{J_1^{P2}} = 240$	$T_{J_2^{P2}} = 420$
$T_{buffer\ offset\ J_1^{P1}}$ =120	$T_{buffer\ offset\ J_2^{P1}}$ =210
$T_{buffer\ J_1^{P2}}$ =29.61271	$T_{buffer\ J_2^{P2}}$ =62.40213
Buffer minimization of: 75.32%	Buffer minimization of: 70.28%
$T_{J_3^{P2}}$ =420	$T_{J_4^{P2}}$ =300
$T_{buffer\ offset\ J_3^{P1}}$ =210	$T_{buffer\ offset\ J_4^{P1}}$ =150
$T_{buffer\ J_3^{P2}}$ =83.01767	$T_{buffer\ J_4^{P2}}$ =37.00178
Buffer minimization of: 60.46%	Buffer minimization of: 75.33%
$T_{J_5^{P2}}$ =420	$T_{J_6^{P2}}$ =420

$T_{buffer\ \ offset\ J_5^{P1}}$ =210	$T_{buffer\ \ offset\ J_6^{P1}}$ =210
$T_{buffer\ \ J_5^{P2}}$ =79.01395	$T_{buffer\ \ J_6^{P2}}$ =83.82293
Buffer minimization of: 81.18%	Buffer minimization of: 80.23%
$T_{J_7^{P2}}$ =180	
$T_{buffer\ \ offset\ J_1^{P2}}$ =90	
$T_{buffer\ \ J_7^{P2}}$ =29.4158	
Buffer minimization of: 67.31%	

Table 5. Buffer minimization for the Task Set in Project 2

Task list for Project 3	
$T_{J_1^{P3}}$ = 360	$T_{J_2^{P3}}$ = 180
$T_{buffer\ \ offset\ J_1^{P3}}$ =180	$T_{buffer\ \ offset\ J_2^{P3}}$ =90
$T_{buffer\ \ J_1^{P3}}$ =53.65919	$T_{buffer\ \ J_2^{P3}}$ =22.20353
Buffer minimization of: 75.32%	Buffer minimization of: 70.28%
$T_{J_3^{P3}}$ =240	$T_{J_4^{P32}}$ =240
$T_{buffer\ \ offset\ J_3^{P3}}$ =120	$T_{buffer\ \ offset\ J_4^{P3}}$ =120
$T_{buffer\ \ J_3^{P3}}$ =38.105065	$T_{buffer\ \ J_4^{P3}}$ =41.61271
Buffer minimization of: 60.46%	Buffer minimization of: 75.33%
$T_{J_5^{P3}}$ =360	$T_{J_6^{P3}}$ =120
$T_{buffer\ \ offset\ J_5^{P3}}$ =180	$T_{buffer\ \ offset\ J_6^{P1}}$ =60
$T_{buffer\ \ J_5^{P3}}$ =69.61934	$T_{buffer\ \ J_6^{P3}}$ =21.40524
Buffer minimization of: 81.18%	Buffer minimization of: 80.23%
$T_{J_7^{P3}}$ =540	$T_{J_8^{P3}}$ =180
$T_{buffer\ \ offset\ J_7^{P3}}$ =270	$T_{buffer\ \ offset\ J_8^{P3}}$ =90
$T_{buffer\ \ J_7^{P3}}$ =130.78144	$T_{buffer\ \ J_8^{P3}}$ =31.20353
Buffer minimization of: 67.31%	Buffer minimization of: 65.33%
$T_{J_9^{P3}}$ =180	
$T_{buffer\ \ offset\ J_9^{P3}}$ =90	
$T_{buffer\ \ J_9^{P3}}$ =22.329605	
Buffer minimization of: 75.22%	

Table 6. Buffer minimization for the Task Set in Project 3

V. RELATED SOLUTIONS

Several commercial implementations have been developed for RCPS [18][19][20]: CA-SuperProject, Time Line, Project Scheduler, Microsoft Project, Microsoft Primavera, of which the last two software tools being of greater importance and wider usage. Microsoft Project and Microsoft Primavera offer normal scheduling processes: Critical Path Scheduling (CPM), Critical Chain Scheduling, Gantt charts, Program Evaluation and Review Techniques (PERT) [18][19]. Some basic functionalities are of main interest for Primavera P3: Automatic Scheduling and Leveling, Progress Spotlight and Progress Update, Resource Assignments. As for Microsoft Project, of interest are: resource capacities and requirements are modeled as aggregated workloads, resource allocation [19]. Several drawbacks have been identified for the given scheduling methods in activity integration and resource planning. Thus, due leveling techniques and extension algorithms have been proposed [18][20] to be applied on traditional CPM Scheduling. Despite of the obtained improvements (prioritization efficiency, idle resources planning, resource leveling) [18][20], some limitations still need to be taken into account: no multi-tasking or reusable resources considerations [18].

Similary, a research – based commercial tool has been regarded for comparison. ProTrack (acronym for Project Tracking) is a software engineering tool, developed as an alternative to existing project scheduling and tracking software tools, based on dynamic scheduling principles [7]. Its main dynamic scheduling-derived functionalities are: baseline scheduling, schedule risk analysis and project control. In the past few years, three versions have been deployed. The last deployed version (ProTrack 3.0 – 2012) incorporates some advanced features, where of interest to the current research are: Automatic Project Generation and Automatic Resource Generation.

VI. CONCLUSIONS

The current research proposes an RCPSP extension based on employee’s profile. The objective function has been defined as task duration minimization based on buffer management. A model of employee profile extracted from the NJC Job Evaluation Scheme and mental factors (stress, intellectual performance) has been designed for task buffer constraints’ definition. Our results prove that an average duration of 70% buffer minimization can be obtained if the WIZO model is applied in project task scheduling.

From a commercial perspective, based on the assumptions described, we consider the WIZO task allocation algorithm more employee-oriented, as constraints are derived from organizational roles and mental effort distribution required to accomplish tasks, while ProTrack offers a more process-oriented perspective, based on tasks operational characteristics (duration, costs).

From the task allocation perspective, the WIZO model can be regarded as a ProTrack alternative due to the following characteristics:

- From the *precedence relations* perspective, ProTrack measures the number of links between activities by how close the project network lies to a completely parallel (no links) or completely serial (maximum number of links) project, while WIZO defines precedence constraints by measuring the compatibility of successive project tasks based on the intellectual effort

- From the *activity constraints* perspective, the minimal project time window is equal to the critical path, while the maximum time window can be extended to the double of the critical path, with constraints randomly assigned in this time window interval. WIZO considers the minimal project time window equal to the total duration of project tasks, while the maximum time window is calculated based on the BMT, where a predefined buffer is assigned to every activity of the project chain.
- From the *resource demand* point of view, ProTrack considers two metrics referenced as resource demand values (average demand and maximum demand) calculated by the number of units requested by the activity. WIZO defines the unit of demanded resources based on organizational skills provided by the employee role required to accomplish the activity. The maximum and the average resource demand of the task are described by the level of competences achieved and submitted through auto-rating process.

As constraints and limitations, the following assumptions need to be mentioned:

- lack of user-acceptance metric regarding self-evaluation
- equal duration for all projects
- same role for the user for all the competing projects
- buffer composition weights randomly chosen

Therefore, some further development and extensions should be considered:

- control loop for model robustness
- scaling applications for the different duration time, multiple roles for a user on different projects, teams of users (collaboration)
- cognitive profile modeling based on ergonomic factor measurement (e.g. stress estimation from retina/iris scan)
- optimization algorithms for task allocation (GA)

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