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TRADING OFF TIME AND MONEY RESOURCES: AN ACTIVITY-BASED FLEXIBLE APPROACH TO PROJECT MANAGEMENT

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Abstract. This paper contributes to the resurgent literature in project management by specifically targeting the scheduling of labor-intensive projects. It investigates a crucial issue that has so far remained largely ignored, namely that of the full substitutability of human resources. Current methods assume either fixed activity durations or full resource equivalence with respect to decreasing the time to accomplish bottleneck tasks. Full substitutability is generally assumed for the sake of algorithmic convenience. This paper paves the way for doing away with this simplistic assumption and its biases.

We first develop a model of the influence of increased human resources on task completion. We then move to incorporate this functional modeling into the context of optimization-based project management. Finally, we illustrate our approach with an application to a real software development project.

Key words: time-cost tradeoff analysis, labor and staff planning, project management, activity network

INTRODUCTION

The issue of effective project management is a most important one and offers the potential of a significant contribution to a nation's economy. Thus, it resurfaces periodically as an important topic in theoretical journals as well as technical periodicals. For instance, a recent issue of the newsletter of the Decision Sciences Institute, *Decision Line* (March 1996), contains an entire feature article devoted to the proposition that Information Science (IS) would benefit greatly from improved project management capabilities [Eliot 1996]. Even though the scope of our approach is fairly general, IS is certainly one of the most conspicuous areas of application.

The current methods for project management are primarily the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). Over time, these methods have come to be viewed as fairly effective tools in managing projects ranging from construction to high-tech specialized systems development [Sweet 1994, Shelmerdine 1989, Gerber 1988]. Still, some problems related to project management are not explicitly addressed by these methods. Specifically, issues of resource allocation are not adequately incorporated into the PERT/CPM analysis [Kimbler 1993]. As a result, some of the current methods are limited in scope because they fail to address, either conceptually or computationally, the issues of modeling resource skills and tradeoffs. The most important of these is the tradeoff of time and money resources, which has to be addressed at the initial method design stage to provide for efficient and flexible project management at the implementation stage. A noted work by Patterson, Talbot, Slowinski and Weglartz [1990] provides a backtracking algorithm for solving resource-constrained scheduling problems. However, the approach they adopt discusses general classes of resources (renewable, non-renewable, and doubly constrained) and does not address the task type or the impact an additional labor allocation will have on the cost and completion time.

The purpose of this paper is to provide a project management model capable of addressing resource allocation issues from a different perspective than that of present algorithms. As pointed out by Adler, Mandelbaum, Nguyen and Schwerer [1995], current methods assume that projects are primarily composed of idiosyncratic, unprogrammable tasks, while, in reality, even product development tasks may be amenable to systematic characterization. We join the efforts of these authors in putting forth a mechanism for more realistic and more effective modeling of task characteristics. However, while Adler *et al.* are primarily preoccupied with the economies inherent in acknowledging task similarities and simultaneities, the purpose of the present research is to address basic errors in the modeling of the impact of incremental resource allocation to bottleneck activities. The model incorporates the effect labor (or additionally allocated labor) has on task and project duration. It provides a tool to control for task and project duration and for completion cost, subject to labor allocation decisions. Issues of task characteristics, available labor, labor type proficiency levels, labor sourcing costs, and allocation decisions of labor per task are considered in evaluating task and project completion. The inclusion of additional labor resources is indirectly taken into account by the experimental design of Adler *et al.* [1995]; our approach accounts for it directly by modeling the effect of additional labor sources under the various categories of work complementarity. For greater generality, the model will utilize the common PERT/CPM scheduling formulation of project activities.

The first section provides a synoptic view of the relationship between resource allocation decisions, task types and task completion, and presents a mathematical formulation of the impact the mode of resource allocation has on task and project completion. The second section discusses task calibration and the relationship between the completion time of a task and the resources allocated toward its completion. In the third section the mathematical formulations are extended into a model capable of analyzing task and project responses to labor allocation decisions. The suggested method is employed in the fourth section to analyze the implementation of a new software implementation project in the financial aid office of Kent State University. The fifth section provides some general suggestions for future research and directs attention to the significance of a skilled labor force.

SECTION I: TASK COMPLETION, TASK TYPE AND RESOURCE ALLOCATION DECISIONS

Project Management and Task Completion

In the process of project management, the decision-maker encounters time-, resource-, and cost-related decisions and constraints. Since monetary resources *as well as time* are both scarce, project managers should recognize the importance of these elements and their relationship to each other. It is notable that, in most cases, labor and time are, to some extent, interchangeable resources. However, the relationship between the two factors originates from the nature of the task [Brooks 1982, Heckman & Oldham 1980].

Some ideal tasks suggest a linear (or close to linear) interchangeability. For instance, agricultural-type tasks (manual crop picking) or basic construction work (painting) constitute good examples of such tasks. Near-linear interchangeability originates from the nature of the task. When the task can be partitioned among a number of workers without any need for communication between them, the allocation problem will be limited to an almost linear tradeoff between time and labor (figure 1). The decision-maker will be able to perform an educated analysis and, given a reasonable amount of knowledge about the cost of the appropriate labor category, make a decision about the task cost and duration. However, Brooks [1982] has questioned the assumption of perfect interchangeability and has himself been quoted in many recent studies [e.g., Abdel-Hamid & Madnick 1990, Adler *et al.* 1995].

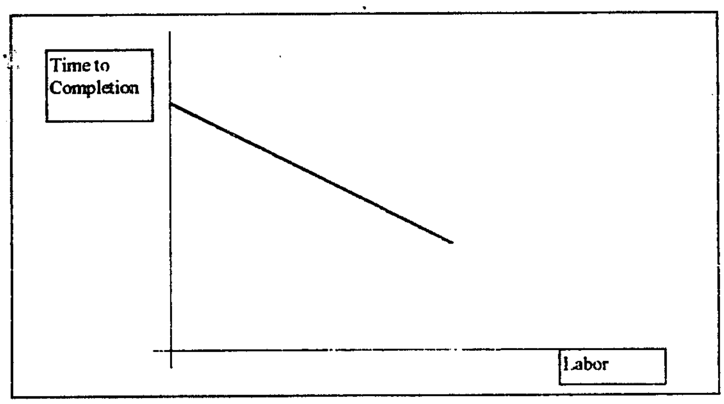

Figure 1 – Tasks with linear interchangeability

The fact is that some tasks *cannot* be partitioned among workers. A classic example of this second type of task is the gestation period of a human child. Under normal condition, child-bearing takes nine months. Allocation of additional "labor resources" to the process will provide no (significant) change (figure 2). Some computer programming and debugging activities have the characteristics of a non-partitioned or even "partitionable" task. It is important to note that the decision-maker should recognize the characteristics of such tasks, since the implication of their nature is that an additional labor allocation will not reduce task duration, and therefore will only increase a task's completion cost.

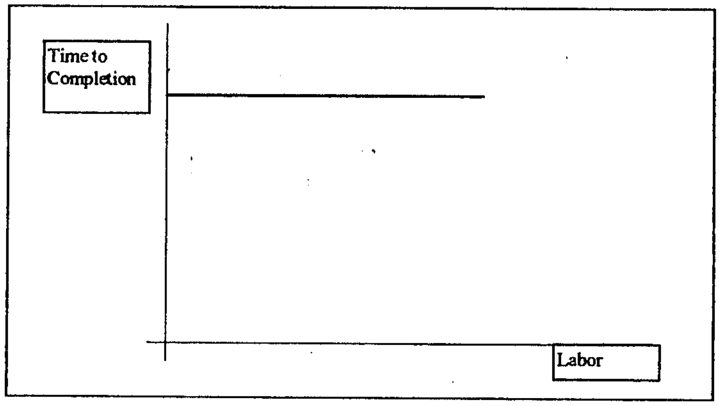

Figure 2 – Non-Partitioned Tasks

A third type of task pertains to those that *can* be partitioned, but which require communication among subtask performers (labor). In this case, additional resources allocated toward improvement in task completion time will generate a decreasing marginal improvement (figure 3). A large group of task types may fall into this category. They range from cement-pouring in construction to well-structured programming assignments in high-tech industries.

The above task characteristics suggest that *communication* can improve performance and reduce completion time. However, communication can sometimes be a burden that translates into increased completion time. An example of this fourth type of task is the special training process that must be completed when additional workers join a task team. The experienced team members will have to allocate some of their time to accommodate the entry of the new "potential productivity resources," thus shifting their attention from their primary objective of task completion (figure 4).

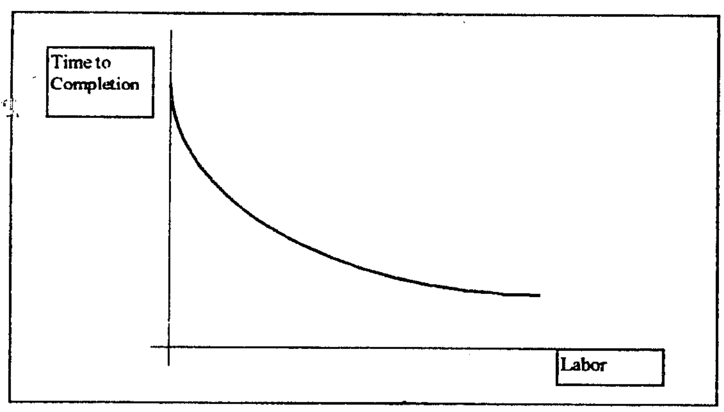

Figure 3 – Partitioned Tasks *without* costly communication

These three task types suggest that, by modeling a task as a function of the resources allocated to its completion, a project manager could express, and sometimes gain knowledge about, the project's expected duration, staffing, and cost. Moreover, the popular PERT and CPM charts that could be generated using sensitivity analysis may provide information about the project duration under different allocation or cost constraints, since this sensitivity analysis of the tasks would be undertaken with respect to the availability of labor resources. The following discussion presents a mathematical formulation of task completion time as an implicit function of task type and an explicit function of resource allocation.

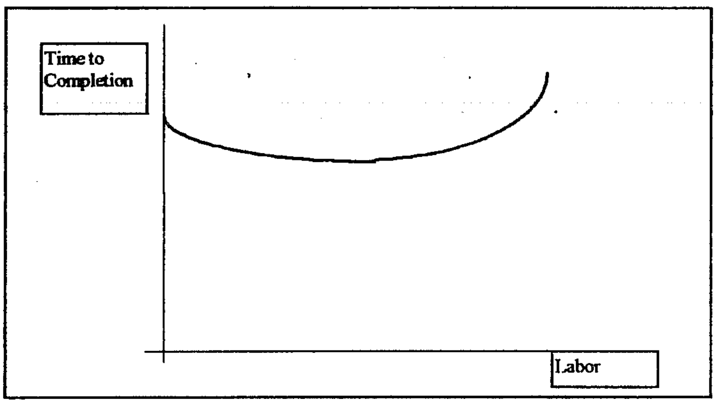

Figure 4 – Partitioned Tasks *with* costly communication

Formulating Task Duration as a Function of Resource Allocation and Task Type

In order to consider the effect resource allocation has on projects' duration and total cost, and also to provide insights about the sensitivity of the project's tasks to changes in inputs, the following variables will be considered[1]:

i	A counter for tasks ($i = 1,2...,n$).
x_i	The number of employees assigned to task i.
t_i	The time (in days) to complete assignment i by x_i employees.
T_i	Calibrated duration of task i (in days).[2]

The nature of the task is an important factor. As mentioned above, the relevant task categories (partitioned tasks, non-partitioned tasks, and tasks with interchangeable resources with costly or without costly communication) should provide a general scope for analyzing allocation influences. The following formulations describe the time for completion of task *i* as dependent on the task type and based on resource allocation decisions.

A *partitioned* task calibrated at T_i will be linearly sensitive to resource and labor allocation at the limits. The time to completion will therefore be formulated in the following general form:

$$t_i = \frac{T_i}{x_i}, \text{ for all } x_i \geq 1 \qquad (1)$$

On the other hand, a *non-partitioned* task calibrated at T_i will not be sensitive to resource allocation. The time to completion will therefore be formulated as:

$$t_i = T_i, \text{ for all } x_i \geq 1 \qquad (2)$$

In the case of a task with interchangeable resources and *without* costly communication calibrated at T_i, the completion time will be non-linearly sensitive to resource allocation. Additionally, the skill or performance level of the resources should be considered. The time to completion can be approximated using the following formulation:

$$t_i = \frac{T_i}{\log_\alpha(\alpha \cdot x_i + \alpha) - 1} \qquad (3)$$

This formulation was developed in order to capture some of the specifics of resource allocation. The formulation captures the diminishing marginal contribution of additional labor resources assigned to the task. Only if the number of the workers assigned to the task were zero would the completion time be undefined (due to a division by zero). Another important interpretation of the value of α is that it is an index for labor productivity or a *performance index*.[3] Interestingly, in the common case in which the value 2 is assigned to α, doubling the labor force decreases the task duration by about 35%[4] and tripling the labor force cuts down the task duration only by half. The interpretation of α as a performance index suggests that each planner can use this value for specific interpretations of the PERT or CPM to his or

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[1] The formulation presents the case of a single labor source. Multiple types of labor sources are discussed in the fourth section of the paper.
[2] The *calibrated duration parameter* will be discussed in the following section.
[3] A more detailed discussion of the *Performance Index* is included in Section 5.

her own special case and/or specific projects. If one considers the value of α as expressing the performance capabilities of his or her labor force, a less skilled labor force with performance index of β should have β>α. Also, more skilled personnel should have a performance index γ, where γ<α. In the case of uncertainty or that of a new type of project, we recommend setting α=2 as an initial parameter and a benchmark of comparison with β and γ.

If the planner does not believe that the performance index should always be 2 (the common α), the case of a single worker becomes a special case and the formula takes on the general form:

$$t_i = \begin{cases} T_i & \text{if} \quad x_i = 1 \\ \dfrac{T_i}{\log_\alpha(\alpha \cdot x_i + \alpha) - 1} & \text{if} \quad x_i > 1 \end{cases} \tag{3a}$$

Last, but not least, the fourth case of interchangeable resources *with* costly communication is probably the hardest to quantify. As convincingly shown by Heckman and Oldham [1980:157], a task calibrated at T_i will have a completion time that is not linearly sensitive to resource allocation and also contains a local minimum point. The time to completion can be approximated using the following formulation:

$$t_i = \begin{cases} T_i & \text{if} \quad x_i = 1 \\ \dfrac{T_i}{-\left(x_i^2\right) + \phi \cdot x_i} & \text{if} \quad x_i > 1 \end{cases} \tag{4}$$

where ϕ is an index that translates the increased costs of communication to an increasing denominator value (up to a certain maximum point). Wherever communication is costly, additional resource allocations will decrease the task duration to a local minimum and then increase it again. The fact that the productivity of the resources allotted may be increasing to a certain maximal level and then decreasing is well rendered by this model.

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[4] Thus giving a ratio of 1.58 or 1.6 for 2 workers. Intriguingly, this ratio of 1.6:1 or 5:3 is very close to the "golden ratio" of the ancient Aegeans and Greeks.

This discussion about the nature of α in partitioned tasks with communication and about ϕ in the case of a partitioned task with costly communication is theoretic in nature. It aimed at developing some insight into the issue of resource allocation in a complex project environment. The mathematical representation is meant to be general. Adjusting it to fit specific cases is a challenge, and an effort to do so will be presented in the following sections of this paper. The next section presents the issue of calibrating task duration at T_i and discusses the importance of an effective calibration in resource-allocation type problems.

SECTION II: CALIBRATING TASKS, THE INFLUENCE OF TASK CHARACTERISTICS AND MODELING TASK DURATIONS

Calibrating a Task Duration

Network methods assume standard or standardized activity and task completion time. Standardizing or *calibrating* a task as "a task of completion time T_i" touches on an interesting issue. The decision-maker (or the planner) has to assign a duration value for the completion of each project task. The process, however, is ambiguous, since the assumptions embedded in assigning task duration have not been made explicit. Implicit in the scheduling process of evaluating task duration is the assumption that the resources required to perform activities are available in unlimited supply, or at least that sufficient resources are available for the activity to be scheduled between its earliest and latest start dates [Weist & Levy 1977, Pritsker Watters & Wolfe 1969]. The result is a time assignment that originates from resources availability assumptions left hidden in the decision-maker's mind. While the decision-maker is assumed to be knowledgeable about the project's tasks, this lack of explicit modeling and disclosure limits the analysis scope about the task in question and the project as a whole. Duration assignments that originate from unclear resource assumptions will not provide a future basis for analysis. For example, a task scheduled for time t_x with an undisclosed amount of resources may not generate any staffing requirements even when it ought to. Moreover, this schedule cannot provide any information about speeding up the task completion date with an increased labor allocation.

Additionally, cost issues are left out too. When the initial duration assignment or computation does not explicitly account for any information about the precise type of resources employed, cost evaluation and cost control issues are out of the question in most models. Yet, the relationship between labor allocation and task completion has been discussed by economists, and the diminishing marginal return of labor is a well-accepted concept [Vickrey 1964, Heckman 1980]. Incorporating issues of resource allocation into task duration in the context of project management must capture two major factors: *i*) a calibrated task duration at a given resource level, and *ii*) the marginal effect of additional resources allocated toward task completion. The following discussion will present a method for calibrating, and a quantitative procedure for evaluating, the sensitivity of t_i with respect to changes in allocated resources (note that a lower case t_i represents time to completion of task calibrated at T_i under certain allocation decisions).

Calibrating Tasks – Incorporating Task and Labor Characteristics

Calibrating task duration entails that a time value be placed on the task duration according to an explicitly recognizable production resource. At this point, the task type (namely partitioned task, non-partitioned task, interchangeable resource with almost-free communication, and interchangeable resources with costly communication) will provide evidence about the task sensitivity to resource allocation. For example, a task to develop a certain software module can be calibrated for one programmer. If it were calibrated at 40 hours, recognized as a task with *interchangeable resource and free communication,* and the labor skill level is estimated at α=2, then inferences can be made about the marginal effect of additional resource allocation. An additional programmer assigned to this task will shorten its duration by approximately 36% (assuming the same skill level in all programmers).

This framework also allows for cost control. If a programmer's hourly wage is $50, then the allocation of labor and its effect on task completion time and costs can be analyzed on a comparative basis in order to generate a staffing decision. Table 1 presents a summary of the task staffing, duration and cost information:

Number of Programmers	Completion time (Hrs.)	Task Cost ($)
1	40.00	2000.00
2	25.24	2523.72
3	20.00	3000.00
4	17.23	3445.41
5	15.47	3868.53

Table 1 – Staffing, completion time and cost information

This information captures the impact of staffing on cost and duration. At this point, the decision-maker knows the minimum completion cost and the maximum duration. Additionally, this formulation provides a better understanding of allocation and its impact of task completion cost and length.

Ambiguous or implicit assumptions about labor (such as the ones used in current PERT/CPM methods) do not help in evaluating a resource addition's effect on task completion. The information provided in this example suggests that our task formulation can provide insights about the task duration, and also about the cost of speeding up critical activities. This simple example directs the attention to the crucial element in the allocation problem: the calibration of task duration. The proposed calibrating process starts with the recognition of "*the most available resource*."[4] In many cases, *the most available resource* embodies the availability of an internal worker; in other cases, it can be that of a project team, or a whole internal department. In practice one has to consider the following rationale:

1. An internal worker is, in most cases, a factor of production assigned to the operation by default. Decisions to provide additional support (whether from internal or external sources) are discretionary.
2. The basic assumption is that the operation is productive at the limits ranging from a staff of 1 unit of production (a worker or a project team) to one's entire staff.[5]

3. Calibrating at one unit of labor will provide a basis for analysis. From this point onward, additional resources can be evaluated according to their marginal contribution to the decrease in t_i.

The initial calibration should therefore be done according to the expected performance of one unit of the most available resource. From this point on, additional allocations of resources can come from different origins with different skills. The following discussion will combine the calibrated task duration variable, (T_i), task characteristics, and allocation decisions in a formulation aimed at evaluating the impact the allocation decisions of different labor types have on task duration and cost.

Performance Differences Among Labor Groups[6]

The formulation of task duration entailing interchangeable resources with necessary communication was presented earlier as being (Equation 5)

$$t_i = \frac{T_i}{\log_\alpha(\alpha \cdot x_i + \alpha) - 1} \qquad (5)$$

This formulation captures the effect a single labor source has on the task duration while implicitly assuming that every additional unit of labor has the same proficiency (or skills). However, this embedded assumption limits the applicability of the formulation to simple cases, primarily because, in complex task environments, the project manager has different skill groups at his or her disposal. For example, a certain programming task can be completed by a department's internal workers at a certain time period, could be contracted out and completed in (presumably) a shorter time period, or given to a group of college students as a project and completed in a longer time period.

Alternatively, the same task can also be divided into subtasks and the different subtasks assigned to different skill groups. In order to provide an analysis of resource allocation with different skills, formulation (5) should be extended so as to capture the characteristics of the different groups available.

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[5] If the lower limit were to be zero units of production, none of the tasks would be completed and T_i would become infinity.

[6] The rest of this paper will limit the analysis scope to tasks characterized by interchangeable resources and necessary communication.

Task Duration with Allocation of Multiple Labor Sources

The time to completion (t_i) of a task calibrated as T_i can be a function of more than one labor source. For example, the project manager can have his internal workers (group 1), hired contractors (group 2), and unskilled laborers such as students (group 3). The time required to complete a task i with multiple labor sources (three in this case) is given by:

$$t_i = \frac{T_i}{\log_\alpha(\alpha \cdot x_{i1} + \alpha) + \log_\beta(\beta \cdot x_{i2} + \beta) + \log_\delta(\gamma \cdot x_{i3} + \gamma) - N} \quad (6)$$

where

t_i is the time to completion of task i according to resource allocation

T_i is the initially calibrated duration for task i

x_{i1} is the number of workers assigned from group 1 to task i

α is the performance index of group 1

x_{i2} is the number of workers assigned from group 2 to task i

β is the performance index of group 2

x_{i3} is the number of workers assigned from group 3 to task i

γ is the performance index of group 3

N is the number of skill groups assigned to the task (3 in this example.)

It is important to note that, if the allocation of labor resources is limited only to group 1 (say, internal workers), the functional form reduces to the simple form of equation 3(a).

Cost Control – Task, and Project Allocation Dependent Valuation

Some apparent benefits originate from this formulation. The first one is that task completion costs can be used in the model. The allocation decision will generate a completion time for the task, and by knowing the cost per unit of labor of every group, the task completion cost will be:

$$TC_{x_i} = t_i \cdot \left[\sum_{j=1}^{3} \left(x_{ij} \cdot c_{ij} \right) \right] \tag{7}$$

where

x_{ij} is the number of employees from group j assigned to task i

c_{ij} is the cost of employee from group j assigned to task i (per time period)

And for a project consisting of n tasks the total cost will be

$$TC_{\text{Project}} = \sum_{i=1}^{n} t_i \cdot \left[\sum_{j=1}^{3} \left(x_{ij} \cdot c_{ij} \right) \right] \tag{8}$$

In addition to cost control, the effect of the allocation decision on the project critical path (CP) and duration can be evaluated. The following discussion focuses on the development of a model that incorporates resource allocation decisions in tasks and project management, and provides a tool for project duration estimation, cost control, and employment level decisions. Again, the analysis will be limited in scope to tasks with interchangeable resources (and no cost of communication). However, the case of multiple labor sources with different skill levels will be taken into account by our approach.

SECTION III: A METHOD FOR INCORPORATING RESOURCE ALLOCATION INTO CPM AND PERT METHODS

Project Time Analysis – Using PERT/CPM

Using PERT or CPM, a project manager can calculate a time schedule for a network of project tasks [Glaser 1984]. The process consists of the following steps:

- Individual tasks, each with its estimated time of completion, are first interconnected with the others in a network to reflect the relations among them.
- For each task, a schedule is then calculated consisting of a "can start" date according to its relationship with other tasks.

- Following these first two steps, a "must complete" date is calculated according to the scheduled start of succeeding tasks.
- The difference between the calculated time available to complete a task and the estimated time required to complete it - the *slack time* - is calculated. If its slack is zero, a task is assumed to be "critical," and the delay in completing it will consequently delay the full completion of the project.

When using CPM, knowing the scheduled start and completion time for each task is fundamentally important in managing the project. However, as mentioned before, it is unclear how task duration is originally estimated in present-day algorithms and available software packages. In addition, workforce-related factors (such as ability to perform the task and the influence of labor allocation on task duration) are not always accounted for in the PERT/CPM methods [Gutierrez & Kouvelis 1991, Hughes 1986].

Since task duration is, for the most part, a function of the resources allocated to its completion, and since the most significant resource in this discussion is labor, the initial responsibility of a project manager will be to gain understanding about the nature of each task's complexity, coordination requirements, and the resource types needed and available for allocation [Towle 1992]. By analyzing the task-specific characteristics, the decision-maker will be able to identify the task type as one of the four mentioned above (partitioned task, non-partitioned task, interchangeable resources with free communication, and interchangeable resources with costly communication). The importance of categorizing each task in the project according to its status is crucial for the allocation analysis that follows.

Project Management and Control with Task Related Resource Allocation Decisions

Assuming a project made out of n tasks, if the calibrated task duration $T_1 \ldots T_n$ are provided, a certain critical path (CP) will emerge that will dictate the project's duration under the initial allocation assumptions. If, for example, the task schedule suggests that the project has q possible paths (P_1, $P_2, \ldots, Pq$), the CP will then be:

$$CP = \max \{P_1, P_2, \ldots P_q\}.$$

Since $P=f(t_i)$ and $t_i=g(T_i,x_i)$, the project's critical path analysis can be conducted in terms of the resource quantity and type allocated to each individual task.

The classical PERT/CPM literature [Schoroeder 1993, Starr 1995] provides a method for analyzing the sensitivity of the CP to changes in task times and the probability of completing a task in a certain period of time. However, the analysis originates from rather ambiguous input provided by the planner that lists three values for every task duration; i.e., optimistic, pessimistic, and realistic duration. Using traditional methods, no information is provided about the resources allocated toward task completion, their cost, and the marginal effect of additional labor on task duration. As shown below, the model of the effect of adding resources or manpower on task duration developed in this paper can help determine the influence of variability in labor availability on the project duration and the CP that emerges.

Using the following nomenclature:

P_p	is a certain path in the project's task schedule, $p=\{1,\ldots,q\}$
T_{ip}	is a project task (at the benchmark duration level) included in a path p
i	is a counter of tasks, $i=1,2,\ldots n$
j	is the type of labor group available, j=1,2,...N
α_j	is the proficiency level of group j, where $\alpha_j>1$.
x_{ij}	is the number of units of production (labor) of group j assigned to task i
C_{ij}	is the cost of one unit of production from group j assigned to task i
MRL_{ij}	(Max. Resource Level) maximum resources of type j available for task i

TC	project's total cost
$BUDGET$	budgeted (maximum) expenditure level

The general format of our proposed approach to project scheduling is as follows:

Minimize: $$TC_{Project} = \sum_{i=1}^{n} t_i \cdot \left[\sum_{j=1}^{N} \left(x_{ij} \cdot c_{ij} \right) \right]$$

s.t.: $x_{i,j} \geq 0$

$x_{i,j} \leq MRL_{ij}$

This problem formulation suggests that the model will be able to generate a per-task staffing schedule for the project. Additionally, if labor sources are limited in availability, the staffing schedule is going to incorporate these constraints into the staffing decision. With minor modification, the formulation can be employed to include cost control measures. The following section will present a potential way to employ the approach for analyzing a project management assignment in the Financial Aid Office at Kent State University.

SECTION IV: RESOURCE ALLOCATION-BASED CPM MODEL AND ITS APPLICATION TO PROJECT MANAGEMENT AT KENT STATE UNIVERSITY

Project Description

The method was tested on an actual software project. The trial project applied the case presented in expression (6) and involved the implementation of new application software to support the Financial Aid Office of Kent State University. A new student information system software package was purchased and the project entailed: *i*) converting the existing data to the new system; ii) developing programs to provide additional capacities not included in the package; iii) reviewing overall performance, documenting the systems' functions, and technical support operations; iv) testing the package programs and developing a procedures manual for the Financial Aid Office.

In our pilot study, the project's tasks are categorized as tasks with interchangeable resources and *without* costly communications (as formulated in expressions 5 and 6). The reason for defining these tasks as such originates from the manager's knowledge about the task requirements and characteristics. In this case, it is presumed that, if a worker is assigned to a task, it is because he or she already appears qualified and will not need on-site training. Therefore, external consultants and student workers are hired only if they can prove that they will not require on-site training. This suggests that labor productivity will exhibit diminishing returns. However, it does not by itself imply that new labor assignments will necessarily require additional resource allocation to accommodate the new workers assigned to the task.

The project activity codes, calibrated duration (in days) and predecessor activities are shown in Table 2 below.[7]

ID	Name	Duration	Predecessor
1	Complete Conversion Progra	42	
2	WR23 SFCOMPL	14	1
3	WR24 SFLNUP	25	2
4	WR25 SFPELAW	51	3
5	WR27 PARS SBA453	49	1
6	WR29 PARS SBA455	34	5
7	WR31 SFLABEL	16	6
8	WR32 SFPS5ES	29	1
9	WR33 SFCWS	67	8
10	WR96 SFDELET	65	9
11	WR104 SFOIGRP	92	10
12	Review SIS Fin Aid Jobs	101	4,7,11
13	Develop Procedures Manual	20	12

Table 2 – Project activities, duration and predecessors

The CPM diagram for this project is shown below. Since this is a relatively small project, we can identify all the paths easily. More complex projects may require the use of a CPM software package to identify the paths. The paths available in this case are P1 (tasks 1,2,3,4,12,13), P2 (tasks 1,5,6,7,12,13) and P3 (tasks 1,8,9,10,11,12,13), which is the Critical Path.

[7] For a short description of the coded tasks, see Appendix 1.

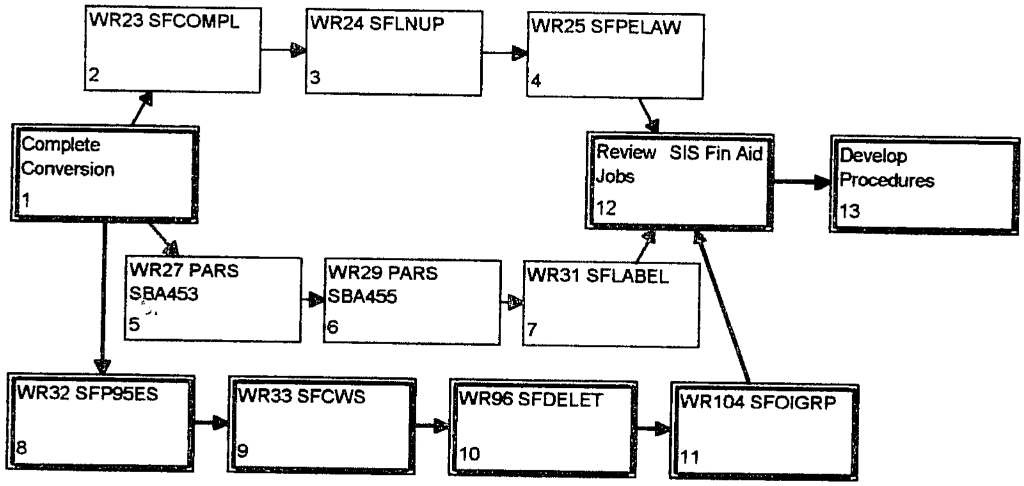

Figure 5 – CPM diagram

Characteristics of Available Labor Resources (Cost and Performance)

The labor resources made available for the completion of this project were the computer services department's internal employees, a group of external consultants hired per task and compensated on a daily basis, and some university students who had programming skills and were paid an hourly student rate[8]. In order to calculate the duration of each activity based on the number of resources assigned, it is first necessary to estimate the duration of the activity if completed by one average internal employee. These estimates can be based on experience, expert opinion, or other techniques such as "function point analysis" for information systems development [Elmaghraby 1977].[9]

Another important factor in this analysis is the labor cost. The cost of each resource (C_{ij}) was relatively easy to estimate. The competitive rate for contract employees was determined with a few phone calls to companies supplying contract employees. Internal costs were either known or were available from the accounting group. Student employee costs were provided from the university's

[8] We assume that the skill level of each group is homogeneous. This assumption is particularly accurate for the external consultants hired for specific and well-defined skills, and also for those students hired upon proving specific skills in the subject matter. Internal employees are assumed to be a homogeneous group according to their previously proven capabilities.

[9] It is important to note here that calibrating the task duration can be a challenging task by itself. However, the focus provided by the request to calibrate according to one unit of *the most available resource* focuses the analysis. Unlike traditional CPM methods that assign task duration without determining their reasons, this is an improvement for project managers.

payroll office. The labor resource costs were \$200, \$360 and \$50 *per diem* for internal workers, external workers, and students, respectively. [10]

The determination of the performance index was more complicated. Knowledge about the nature of the task and the labor source characteristics can be extremely useful in this stage. For example, if one employee can complete a certain task in 42 days, and if the manager estimates that two employees may be able to complete the task in about 27 days, a performance index can be found (assuming the task type has been identified correctly). If we employ the formulation suggested earlier and solve for the performance index (α),[11] we obtain a good estimator of the group's performance index relative to selected tasks.

An estimation of the groups' performance indices revealed that the external contractors had better performance indices than the internal workers (probably due to their level of task specialization). Students had the lowest performance index between the groups. [12] When the activities are all of similar types, the performance index may be constant across all activities for a given resource type. The labor resource performance indices obtained in our case were 2, 1.2, and 10 for internal workers, external workers, and students respectively. [13]

Model Formulation and Constraints

The objective of the project manager of our pilot study was to minimize the project's total cost and to limit the duration to less than 90 days (a period of 85-90 days was considered to be an acceptable range). This constraint suggested that the critical path, or the longest in duration of all potential paths, would be restricted to this value. Additionally, the demand was that the staffing process included *at least* one internal university worker for every task (for basic control purposes). Non negativity constraint for labor sources was added, and cost constraints were included. The formulation was therefore as follows:

[10] The cost of a labor source was identical across tasks in this pilot study, since most of the task-required skills were similar and did not justify major changes in compensation.
[11] Using the formula for task duration of task with *interchangeable* resources presented earlier in the paper.
[12] Note that better performance index values correspond to smaller log bases and vice versa.
[13] The performance index can be identical across tasks when most of the tasks are similar with respect to the skills expected from the workers.

Minimize: $$TC\ \text{Project} = \sum_{i=1}^{13} t_i \cdot \left[\sum_{j=1}^{3} \left(x_{ij} \cdot c_{ij} \right) \right]$$

Where:

s.t.: $90 > \text{Max}\{ P_i \} > 85$

$x_{i,j} \geq 0$

$x_{i,1} > 1$

$c_{ij} = C_{ij}$

The model did not enforce integer constraints on the labor force, although such a constraint should have been expected. The exploratory nature of this model and its use in an experimental manner did not require a strict limitation to integer-type staffing. Additionally, forcing integer programming in this case would limit the sensitivity analysis scope. Future application could and should incorporate integer constraints into the model formulation.

Results

The "Solver" included in the *Microsoft Excel* package was used for providing a solution. [14] An optimal solution was found and the following information suggested that the project could be completed in 90 days under the following conditions (Table 3):

[14] The Excel solver follows the branch-and-bound algorithm.

		Staffing			Costs				
Task	**Path Number**	**Internal Workers**	**External Contractors**	**Students**	**Internal Workers**	**External Contractors**	**Students**	**Total**	**Task Dura-tion**
1	1,2,3	3.03	5.14	2.00	5623	17182	929	23734	9.28
2	1	1.75	1.62	2.84	1627	2716	661	5004	4.66
3	1	1.57	0.17	2.63	4229	834	1773	6836	13.46
4	1	1.34	0.00	2.11	9077	0	3579	12656	33.85
5	2	1.52	0.00	2.23	9270	0	3390	12660	30.43
6	2	1.68	0.00	2.51	6685	0	2499	9184	19.88
7	2	1.73	1.59	2.82	1854	3073	756	5683	5.37
8	3	2.07	5.73	3.02	2625	13088	958	16671	6.34
9	3	2.17	5.54	3.05	6393	29426	2254	38073	14.77
10	3	2.16	5.54	3.05	6186	28578	2185	36949	14.32
11	3	2.23	5.51	3.07	9024	40207	3112	52343	20.25
12	1,2,3	2.32	6.70	3.12	9677	50312	3260	63249	20.87
13	1,2,3	2.08	6.21	3.03	1769	9532	646	11947	4.26
Total					74039	194948	26002	294989	

Table 3 – Staffing and cost information

The model provided a solution that would provide a project completion within 90 days while minimizing total cost. Table 4 presents the project's paths and their duration.

Path 1	1	2	3	4	12	13		Total Days
Time	9.28	4.66	13.46	33.85	20.87	4.26		86
Path 2	1	5	6	7	12	13		
Time	9.28	30.43	19.88	5.37	20.87	4.26		90
Path 3	1	8	9	10	11	12	13	
Time	9.28	6.34	14.77	14.32	20.25	20.87	4.26	90

Table 4 – Paths and duration

It is interesting to note that paths 2 and 3 yield a duration of 90 days. This fact should prompt the manager to observe task performance on both paths carefully, since the slack time in all of these tasks in zero. In addition, the model generated per-task staffing requirements for each labor source. This output should assist in making long-term hiring decisions for the project manager. The project's minimized total cost was found to be about $295,000. This is the total expected cost if all goes well.

More importantly, our algorithm provides a tool for evaluating the resources management will have to dedicate to the completion of the project under current resource tradeoff conditions. Any marginal increase in labor force can be evaluated according to its cost and benefit in terms of shortening the project's duration.

SECTION V: SUMMARY, CONCLUSIONS, AND A NOTE ON THE SIGNIFICANCE OF LABOR PERFORMANCE

The issue of effective project management remains at the forefront of the potential contribution to industrial productivity. A strong case can be made as to its centrality to Operations Management, as well as its relevance to the IS field [Eliot 1996]. In an apparent effort to model the economic impact of adding resources to the central activities of a project, recent work by Adler *et al.* [1995] has conceptualized project development as a network in which projects are "jobs" being serviced by resources that are "workstations." Their approach has contributed to accounting for the differential impact of adding resources, but, even though it sheds some light on the issue, it only indirectly confronts the extra coordination effort implied by the addition of new people.

This paper presents an alternative method for project management that concentrates on the task duration and its sensitivity to resource allocation and performance. Our proposition is that time can be saved with the additional expenditure of money. However, monetary resources should purchase more productive labor assets and focus on the best skills that can be bought. While traditional methods have lacked the ability to generate staffing schedules or evaluate the impact additional staffing has on project cost and completion time (according to the task type), the formulation proposed here presents a potential solution to some of these problems. The most significant improvement proposed in this model is its ability to capture the project as a construct of skills purchased at a certain cost and employed toward task completion. A case study undertaken in the context of a software development project illustrates the method (Section 4) and shows how quantitative project analysis may not necessarily have to adopt a non-intuitive stance. As a matter of fact, the adjustments proposed herein represent a fairly intuitive rendering of the basic tradeoffs between time and money resources.

This model should be a source for future research so that its applicability to different types of tasks and projects can be evaluated. Specifically, future research should provide an approach to categorizing a task and assigning a certain type to it. In addition, research should attempt to determine whether a labor group is homogeneous and to evaluate its performance index. A better understanding of these issues will benefit project management considerably by making it more accurate and more capable of analyzing the tradeoffs of time and money in project management.

An important aspect that the model sets forth is the ability to capture labor-specific parameters and to evaluate their impact on a certain project's cost and duration. Quantifying the *performance index* in this sense is a relatively new concept and requires close attention. In general, the performance index originates from a certain evaluation of the labor force skill level. The initial formulation employed the value of 2 as an approximation. Many managers have concurred with this initial formulation and have suggested that, in specific task environments, this intuition is very close to reality. The relevance of the performance index, however, is gaining importance with the globalization of the field of project management. Currently, in many hi-tech projects labor is transferable, and it therefore does not follow that a project in a certain country will necessarily include that country's labor resources. In areas where labor is fully transferable, the local labor resources may not be utilized if they are not at a certain level of performance. In this sense, considering hi-tech development projects in the Middle East, for example, suggests that, due to recent trends of labor transferability, the proficiency of local labor resources must be improved to secure its employability in a variety of regional development projects.

The relationship between labor skills and task completion sheds light on a general issue that must be addressed in the context of international project management. The decision of large hi-tech corporations to enter markets in the Middle East necessitates improved labor performance in these countries. The alternative to labor development will be either loss of international projects or increased levels of foreign skilled labor.

While the issue of performance is often discussed in the literature [see a detailed discussion in Stolovitch & Keeps, 1992] relating human performance measures to resource-constrained project management is not frequently discussed. The increased potential for development in certain areas (such as the Middle East) suggests that some development projects are likely to take place. In this sense, if local labor is proficient, the potential exists for the local economy to gain from such development. The incentive therefore exists to develop Human Performance (HP) and Human Performance Technology (HPT) [Stolovitch & Keeps 1992, Austin & Titus, 1984]. This paper has presented a case of incorporating the performance index in a specific software development project in North-America. By considering the insights suggested in this case, and incorporating HPT principles, a better understanding can be gained about the differences of processes of developing and improving HP in the international, and specifically in the Mediterranean arena.

APPENDIX 1: DESCRIPTION OF PROJECT TASKS

WR23 - Convert job SFCOMPL9. Develop specifications, design, code, and test a program(s) to extract all financial aid recipients with Title IV or Nursing loans who have not complied with regulations set by the federal government and the Financial Aid Office.

WR24 - Convert job SFLNUPD8. Develop specifications, design, code, and test a program(s) to validate that an applicant meets all federal and Financial Aid Office requirements to receive a guaranteed student loan. Certify the loan for processing by the guarantor.

WR25 - Convert job SFPELAW9. Develop specifications, design, code, and test a program(s) to add, delete, or modify a Pell Award based on changes in the students' enrolled hours or income status.

WR26(96) - Convert job SFDELET8. Develop specifications, design, code, and test a program(s) to delete financial aid awards for students who do not continue to meet award eligibility requirements throughout the academic term.

WR27 - Convert the SFFILOG9 job. Develop specifications, design, code and test a program(s) to capture scan codes from student financial aid folders and employee IDs for folders being checked out from the main storage location in order to track the folder location.

WR29 - Convert the SF94PAR9 job. Develop specifications, design, code, and test a program(s) to produce reports and award letters for students receiving financial aid awards.

WR31 - Convert the SFLABELS job. Develop specifications, design, code, and test a program(s) to produce file folder labels when PELL need analysis record is created.

WR32 - Convert the SFP95ES9 job. Develop specifications, design, code, and test a program(s) to determine student eligibility for estimated PELL awards, create the award, update the fund detail and produce associated reports.

WR33 - Convert the SFCWS9 job. Develop specifications, design, code, and test a program(s) to update the Financial Aid Award amount used based on the payroll for student workers in the federal work study program.

WR104 - Convert the SFOIGUP9 job. Develop specifications, design, code, and test a program(s) to edit and update the Ohio Instructional Grant award amounts based on an input tape from the Ohio Student Aid Commission.

Review SIS Financial Aid Jobs - For all the jobs included in the purchased system. Modify the Job Control Language to local standards. Test the job, creating example output pages for systems documentation. Create required systems documentation and transfer jobs and programs to production.

Develop Procedures Manuals - Based on the purchased system online screens and jobs and the requested modifications, develop procedures to be followed by the Financial Aid Office in awarding aid to students.

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