ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

Title: Optimal Personnel Allocation for IC Design Projects

Course:

Year: 1989

Author(s): R. Bhatia, M. Fenrick and B. Pathak

Report No: P89001

Abstract: The problem of human resource allocation among design projects in an organization was studied. Four types of human resources are considered, and each project is composed of six different types of tasks. An effectiveness matrix is derived by linking the productivity of each type of human resource to each task as compared with other human resources. The problem was formulated as a Linear Programming Model to obtain an optimal mix of human resources. Optimality is defined as the minimum total design cycle time.
Optimal Personnel Allocation for IC Design Projects

OPTIMAL PERSONNEL ALLOCATION FOR IC DESIGN PROJECTS

R. Bhatia, M. Fenrick, and B. Pathak

EMP - P8901

OPTIMAL PERSONNEL ALLOCATION FOR IC DESIGN PROJECTS

Rohit Bhatia, Michael Fenrick, Bimal Pathak

EAS 543 - Spring 1989
Portland State University

ABSTRACT

This project has examined the problem of allocation of human resources amongst design projects in a organization. Four different types of human resources were considered and each project was assumed to be composed of six different types of tasks. An effectiveness matrix was derived linking the productivity of each type of human resource to each task as compared to the other human resources. This problem was then formulated as an Linear Programming Model with the objective of obtaining an optimal mix of different human resources allocated amongst the different projects where optimality was considered to be a minimum total design cycle time.

1. Introduction

Every integrated circuit (IC) design project can be considered as a set of well-defined tasks that need to be carried out successfully, to implement an IC. Most IC design projects involve a team of engineers and layout designers working together to accomplish the project under the usual contraints of cost, performance and schedule. In addition, a given organization usually has several design projects in progress at any given time. The Engineering Manager responsible for these projects is confronted with the problem of how to assign a group of engineers and layout designers to a set of projects to achieve an optimal mix of engineers and layout designers for each project. This is the problem we hope to address through the use of a generalized LP model for this project.

In this project, we consider four different types of human resources relevant to IC design projects and split each project into six major tasks. Each human resource type is linked to each task through an effectiveness matrix to reflect the productivity of that human resource on each task as compared to other human resources. Given the above framework, this project explores the problem of finding an optimal allocation of these human resources so as to achieve the goal of minimizing the design time for a given set of projects. The approach presented here can be generalized to extend to other environments where the problem can be described in the format used here.

There are some assumptions and limitations involved here in the modeling process. One of the main weaknesses of this approach is the effectiveness matrix itself. The effectiveness matrix is derived from subjective opinions of engineering project managers about how well they think that a certain type of human resource can perform on a given task. We believe that the derivation of this effectiveness matrix is an ideal candidate for Hierarchical Decision Modeling Process. Another weakness of this approach is the inability of the model to handle dependencies amongst tasks in a given project. The inclusion of such dependencies would make the model non-linear.

This report is organized into six sections. The next section defines the terminology used in the modelling process and verbally describes the model. Section 3 outlines the mathematical formulation of the model and describes the various matrices used in it. Then the results obtained from LINDO are discussed and analyzed. Finally, Section 6 presents the conclusions and directions for future work.

2. Model Description

In defining a model for this problem, we found it best to present the model using a matrix based approach. As indicated above, we consider four different types of human resources as they pertain to integrated circuit design projects. Since we are concerned with only the design cycle of the project, we found the following four categories to adequately represent the engineering staffing requirements of IC design projects. Each category is described below :

1) Systems Engineer - A systems engineer is responsible for dealing with architectural issues of an IC and the implicatons for systems in which the given IC is to be used. As today's IC's are extremely complex and being termed as "systems on silicon", this is a very important staffing need for IC projects.

2) Design Engineer - A design engineer as the title implies is responsible for the bulk of the design work required to implement the functionality of the integrated circuit.

3) Layout Designer - A layout designer is primarily concerned with the physical layout of transistors on a die once the circuit design has been completed by the design engineer.

4) Part-time Engineering Assistant - This position is organization specific and since it is used in the organization with which we are familiar, we included it in our model. Primarily, these are students or other part-time workers prinicipally helping the design engineer with simulations, documentation, and other routine but essential tasks that need to be completed.

Each project is considered to be a set of six tasks. Each of the tasks defined below may actually comprise several sub-tasks but in order to keep the model relatively simple, it was required that the excact technical details be hidden underneath the major tasks. The six tasks are :

1) System Design - Here the global architectural issues, timing issues and other system related issues are addressed. System design defines the functionality and behavior of an integrated circuit at its boundary.

2) Logic Design - This task represents the total design effort required to achieve the given funtionality of the IC as defined by the system design. This task is a major part of the IC design process.

3) Logic Simulation - Logic simulation is the process of verification of the logic design to ensure that the design actually implements the required functionality.

4) Circuit Simulation - Circuit simulation is the process of verification of the performance of the logic design to ensure that it meets the performance requirements.

5) Layout - Layout refers to the physical placement and interconnection of the circuits as stipulated by the design on a silicon die.

6) Layout Verification - Finally, layout verification is used to ensure that the layout is correct and corresponds to the circuit design.

Three input matrices are used to describe the model inputs. The *Effectiveness Matrix* relates the effectiveness or productivity of a particular human resource to a particular task. The rows of this matrix are the different human resource categories and the columns of this matrix are the different tasks. Each element of this matrix is a relative measure of the effectiveness. All elements of this matrix have been normalized in each column to 1.0. A measure of 1.0 indicates that the human resource is ideally suited to that task. On the other hand, a measure of 0.0 implies that we do not wish to allocate any human resource of that type to that task. By looking at the columns of this matrix, we can see the relative effectiveness of each human resource category on a particular task. If we have two measures of 0.2 and 1.0 for type A and type B personnel on task T1 then it implies that type A personnel requires 5 times as much time to complete the same amount of task T1 as personnel type B.

The total amount of each type of personnel available for allocation over a given period of time is indicated by the *Availability Vector*. Each row of this vector states the total amount of each human resource type that is available in a given organization. The Availability Vector can be also be interpreted as a manager's estimate of staffing requirements for the projects under consideration based on past experience. The *Requirements Matrix* specifies the total amount of each type of task work that is needed for each project being considered for allocation of personnel. The numbers given in this matrix are estimates of project managers from past experiences assumming each task will be accomplished by the most effective human resource type for that task. Each row of this matrix corresponds to a project and the columns correspond to the different task types.

The model described above for this human resource allocation problem can be easily applied to other environments and is not restricted to IC design. As long as key staffing categories and major tasks can be identified, this modelling technique can be applied to any project oriented organization.

3.1 Model Formulation

Four types of human resources :

H1 - Systems Engineer

H2 - Design Engineer

H3 - Layout Designer

H4 - Part-time Engineering Assistant

Six types of tasks :

T1 - System Design

T2 - Logic Design

T3 - Logic Simulation

T4 - Circuit Simulation

T5 - Layout

T6 - Layout Verification

Input Matrices

Effectiveness Matrix

	T1	T2	T3	T4	T5	T6
H1	e11					e16
H2	e21					e26
H3	e31					e36
H4	e41					e46

where e_{ij} = a measure of effectiveness or productivity of personnel type i on task j

Availability Vector

	Time (man-weeks)
H1	t1
H2	t2
H3	t3
H4	t4

where t_i = total number of man-hours available for allocation of personnel type i during a given period of time.

Requirements Matrix

	T1	T2	T3	T4	T5	T6
Project 1	a11	a12	a13			a16
Project 2	a21					a26
Project 3	a31					a36

where a_{ij} = total amount of estimated work of task type j on project i in man-weeks.

Note that this can be extended for multiple projects, however we will consider only one project in our formulation.

Output Matrix

<u>Allocation Matrix</u>

	T1	T2	T3	T4	T5	T6
H1	x_{11}					x_{16}
H2						
H3						
H4	x_{41}					x_{46}

where x_{ij} = amount time spent on task type j by personnel type i

DECISION VARIABLES

The decision variables for this problem are the elements of the Allocation Matrix i.e. x_{ij}.

OBJECTIVE FUNCTION

1) Minimize the total time required to complete a project
2) Maximize the effectiveness of each personnel type

We believe that the LP model in striving to achieve our first objective should provide an allocation of resources such that the second objective is automatically considered. Hence the second objective is inherent in the first objective.

min z = SUM(x_{ij}) where i = 1 to 4 and j = 1 to 6.

CONSTRAINTS

1) Personnel Availability constraints

SUM (f_{ij} * x_{ij}) <= t_i

where i = 1 to 4 and j = 1 to 6

f_{ij} = a parameter to be derived from the elements of the Effectiveness Matrix.

2) Work Requirement constraints

SUM (x_{ij}) >= a_{1j} for each j = 1 to 6 where i = 1 to 4

3.2 Model Data

The input matrices data values are shown in the tables below. The data in tables 1, 2 and 3 were used for the original LINDO run. The results of this LINDO run are in Appendix A. Then the modified efficiency matrix in Table 4 was used to determine sensitivity of results to changes in the efficiency matrix and results of this are in Appendix B. Similarly modified Availability Vector and Requirements Matrix were also run and their results are in Appendix C and D respectively.

Table 1 - Original Effectiveness Matrix

	T1	T2	T3	T4	T5	T6
H1	1.0	0.5	0.4	0.3	0.1	0.0
H2	0.5	1.0	1.0	1.0	0.5	0.7
H3	0.3	0.4	0.1	0.1	1.0	0.5
H4	0.2	0.3	0.4	0.2	0.1	0.1

Explain how you obtained the values in this matrix

Needs explanation why did you make these modifications.

Table 2 - Original Availability Vector

	Time
H1	90
H2	500
H3	400
H4	1000

Table 3 - Original Requirements Matrix

	T1	T2	T3	T4	T5	T6
Project 1	20	72	36	36	144	60
Project 2	20	72	36	36	144	60
Project 3	20	72	36	36	144	60

Table 4 - Modified Effectiveness Matrix

	T1	T2	T3	T4	T5	T6
H1	1.0	0.5	0.4	0.3	0.1	0.0
H2	0.8	1.0	1.0	1.0	0.5	0.7
H3	0.3	0.5	0.1	0.1	1.0	0.5
H4	0.2	0.5	0.4	0.2	0.1	0.1

Table 5 - Modified Availability Vector

	Time
H1	220
H2	500
H3	400
H4	500

Table 6 - Modified Requirements Matrix

	T1	T2	T3	T4	T5	T6
Project 1	5	85	100	100	50	90
Project 2	50	25	36	36	50	60
Project 3	80	72	36	36	144	60

4. Analysis of Results

The LINDO program successfully found the optimum resource allocation for all three project at 1693.81 man-weeks. The total man-weeks estimated for all three projects was 1990, so the LP model has given us a solution that is 300 man-weeks less than the project managers estimate.

The output of the LP solution is reformatted below to show some of the characteristics of the model.

	T1	T2	T3	T4	T5	T6	
H1	20.00	00.00	00.00	00.00	00.00	00.00	
H2	00.00	00.00	00.00	36.00	64.00	85.71	***Project 1***
H3	00.00	00.00	00.00	00.00	112.0	00.00	
H4	00.00	240.0	90.00	00.00	00.00	00.00	
H1	20.00	00.00	00.00	00.00	00.00	00.00	
H2	00.00	70.85	00.00	36.00	00.00	85.71	***Project 2***
H3	00.00	00.00	00.00	00.00	144.0	00.00	
H4	00.00	3.81	90.00	00.00	00.00	00.00	
H1	20.00	30.00	00.00	00.00	00.00	00.00	
H2	00.00	00.00	00.00	36.00	00.00	85.00	***Project 3***
H3	00.00	00.00	00.00	00.00	144.0	00.00	
H4	00.00	109.0	90.00	00.00	00.00	00.00	

In addition to the reduced man-weeks, we also note that the recommended assignments are what was expected. First, allocation of some of the resources like H1 and H3 look almost trivial. But it actually proves that the management has correctly anticipated projects requirements and hired enough of these resources for all three projects. In this particular problem, H1 resource or system engineers are relatively expensive. The total hours available of these engineers are just barely enough to meet all three projects' requirements. The H3 or layout engineers are very scarce and not readily available. The management has also hired enough of them to meet all three projects' requirements. The rest of the tasks are assigned to design engineers and part-time help. The H2 resource or the design engineers are more versatile and less specilized (in other words, well-rounded) to perform most of the tasks. They are also relatively inexpensive. The category of H4 resources can be thought of as part-time help or rather extra help required to meet the minimum design cycle for all three projects. This variable can be actually used as a measurement of total slack in the system. Suppose if the organization has three projects and a limited numbers of system, designers and layout engineers. The engineering manager can use the current model to estimate what kind of extra help he will require if he wants to minimize his design cycle time. Ofcourse, the assumption here has to be that these new resources will have to go through a learning curve and, thus have a lower efficiency, which is reflected in part-time help category.

The efficeiency matrix is the most critical element in the problem eventhough it is rather subjective. The values in the matrix can be directly attributed to some of the characteristics of the LP model. The zero values for the Aij element in the efficiency matrix will prohibit allocation of i resource to j task because his efficiency is zero. Also, design engineers and part time help are more flexible resources and have several none-zero values in the efficiency matrix. These resources are distributed among several tasks.

Since the efficiency matrix is dependent on an engineering managers subjective judgement, we decided to do some sensitivity analysis with respect to these values. As it turns out that since most of the values are zeroes, and it can not be increased because the engineering manager does not want his expensive and scarce resoures to be utilized for any other tasks but their specialties, it limits the scope of sensitivity analysis. Several LINDO runs were made with different efficiency values for design engineers and layout engineers. It was observed that as the efficiency values were reduced more resources were required to make the LP model feasible. This is natural because if the resources are less productive it requires more resources to do the same task. We also tried to hold the number of design engineers to a constant value and increase the number of part-time help because part- time help is less expensive. This did not turn out to be a viable solution because part-time help has low efficiency values, we would have to hire a lot more part-time help to do the same task of few design engineers.

Other LINDO runs were made with higher available man-weeks for cheaper resources and lower available man-weeks for expensive resources. This results in a higher value of objective function which is the total design time for all projects. In the LP model the expensive resources are more productive than the cheaper resources thus more cheaper resources will take longer time to complete the same projects.

The resource requirement matrix is also a very important element of our LP model. So far we have assumed all projects are of equal size and duration and require same amount of resources. We can change these values to model projects at different phases, too. Suppose project A is in first phase where it requires a lot of system designers and very few layout engineers, and project B could be in the last phase where it requires a lot of layout engineers and very few system designers. This can be easily modeled by changing right-hand- sides of the resource requirement constraints. As long as there are enough resources to go around, LP model will optimally allocate resources appropriately.

5. Conclusions and Future Work

The initial use of this model seems to establish it as a potential way to approach resource allocation to multiple projects. It is simple yet powerful way to model a resource allocation problem. The results of the models should not be taken as an absolute value rather it should be used iteratively focus on a decision goals like 'What resources can I hire to help reduce the design cycle time for all three projects' or 'What is the optimum ratio of system engineers to design engineers to layout engineers', etc.

Obviously, these simple models do not incorporate all the constraints of a real world situation. It does not model sequential nature of various tasks and the order they are completed in. Nor does it attempt to model human behavior and communication problems. Ignoring these important issues, the model is still a very good tool to estimate resources requirement and allocation.

The derivation of the effectveness matrix (efficiency matrix) should have utilized the Hierarchial Decision Modeling techniques, mainly the Pairwise-Comparison-Method. In the project the values were normalized to one which does not accurately model the relative skill levels of various resources.

We believe that the LP model used for the resource allocation problem is a good one. This can be generalized for most organizations. There is a potential for lot of interesting enhancements to the LP model. Actually, it would be nice if one could integrate PCM (Pairwise-Compare-Method) and LINDO to make a commercial package that allows the engineering manager to use it iteratively to sharpen his decision on resource allocation. The LP model can be made more sophisticated and model sequential nature of tasks. But we believe that the simplicity is the key characteristic of the model. Any manager can understand and change the model to his particular situation.

Good observation. See Ph.D. Dissertations by J. Shepherd, A. Sadrian, M.G. Shipley and M. Farahat, all of Univ. of Pittsburgh