IENG6923

Distribution Management

PROJECT

on

Labor Scheduling for WTP Construction Site

by

Kaushal Bharatkumar Prajapati

B00945730

Under the guidance of

J. PEMBERTON CYRUS

Associate Professor

Industrial Engineering Department

Dalhousie University

TABLE OF CONTENTS

TABLE OF FIGURES

1. ABSTRACT

The labour scheduling problem is a critical issue encountered by various organizations worldwide. It requires the optimal allocation of human resources to satisfy operational needs while taking into account factors such as availability, skill requirements, personnel assignments, scheduling limitations and cost restrictions. In this project, I have gone through the major goals of labour scheduling, such as optimizing labour utilization, lowering costs, guaranteeing happiness, and adhering to legal and contractual requirements. This project includes scheduling the required number of daily wage labourers for a WTP (Water Effluent Treatment Plant) construction site over a period of 2 years approximately, while taking into consideration enough constraints, thus minimizing total labour overhead(cost). In conclusion, I optimized labour utilization, increase operational efficiency, while adopting to my formulated mathematical models of optimization, which resulted in better performance and success overall for the construction project. I also employed OpenSolver on the formulated models in Excel to get a feasible and optimal solution for which I made use of the Gurobi Solver engine.

2. INTRODUCTION

The construction of a Water Effluent Treatment Plant is a challenging project that calls for careful planning, coordination, and resource management. One of these essential resources i.e., effective labour management, assures the highest standards of quality and safety throughout construction as well as the timely completion of the project. Here I aimed to maximize productivity, reduce delays, and improve the project's overall efficiency by thoroughly addressing the management of available labourers. This project aims to offer useful insights into labour management strategies that can be used to optimize resource utilization, mitigate risks, and complete project milestones within the specified time and budget constraints through the analysis of industry best practices, case studies, and pertinent research. For this project, I have classified the construction activities into two categories running simultaneously: 1) Site Execution activities (Excavation and pipe-laying for the water intake and delivery system, Construction of structures at the WTP plant site, Construction of intake pump house, construction of OHT (Overhead Tanks), 2) Warehouse activities (loading unloading of pipe, fittings, pumps and valves supply).

2.1 Data Explanation

I have divided the whole construction project, approximately 2 years of length, into three phases based on the labour requirements i.e., 1) Procurement Phase (6 months), 2) High Mobilization Phase (16 months) and 3) De-mobilization Phase (2 months). Procurement Phase is the beginning phase of the project which mainly includes activities corresponding to warehouse like unloading of pipes and fittings supply, pump and valve supply, etc., coming to the warehouse from different vendors and loading them on the trucks to supply them to the sites where needed. In-addition, there will be few construction-works like excavation works for pipe-laying and some components of the WTP starting at the site as well. Thus, during the procurement period major requirement of labourers will be at the warehouse more than that of the construction site. During the second phase, a large amount of construction work will start on the site needing a greater number of labourers as the construction work will be at its peak and thus the name ‘High-mobilization’ phase. And the last phase is the end phase of the project in which small activities like commissioning, QA, relocating the remaining from site to the new site, etc., are involved. Hence, the labour requirement for that will be the lowest of all three phases and the company will be relocating the labourers from that site to a new site, hence

‘De-mobilization’ phase. Additionally, I have considered two categories of labourers -Skilled and Unskilled. Skilled have the skills to do electric works and supervising the sites. And, I have considered 18 CAD and 22 CAD as hourly wages for Un-skilled and Skilled construction labourers respectively as per today’s labour market rules [9]. Besides this, I have taken 1 shift to be 8 hours long. Activities involved throughout the construction project are mentioned below with the labour requirements as well:

Activities			Phase 1		Phase 2		Phase 3	
			Skilled	Un-skilled	Skilled	Un-skilled	Skilled	Un-skilled
Execution	Pipeline	Trenching	1	3	5	10	0	0
		Pipe-laying	1	3	5	10	0	0
	WTP Components Construction	Canal Trenching	1	3	5	15	0	0
		OHT and GLT Construction	2	3	5	25	2	6
		Intake well	1	3	5	10	0	0
		Pump house	1	3	5	10	1	2
		Clarifier	0	0	5	10	0	0
		Chlorinator	0	0	5	10	0	0
		Cascade Aerator	0	0	5	10	0	0
		Sand filter	0	0	5	10	0	0
		water storage tanks	1	2	5	10	0	0
		valve fittings	0	0	5	10	0	0
		electrical works	0	0	3	10	0	0
		Alum mixer	0	0	2	10	0	0
		Instrumentation system for SCADA	1	0	5	0	2	0
		Washing filter beds	1	0	4	20	0	0
Supply		Pipe and fittings un-loading	1	5	2	10	0	0
		Site Inspection	1	0	2	10	0	0
		Crane Operating	1	0	4	0	1	0
Total			13	25	82	200	6	8

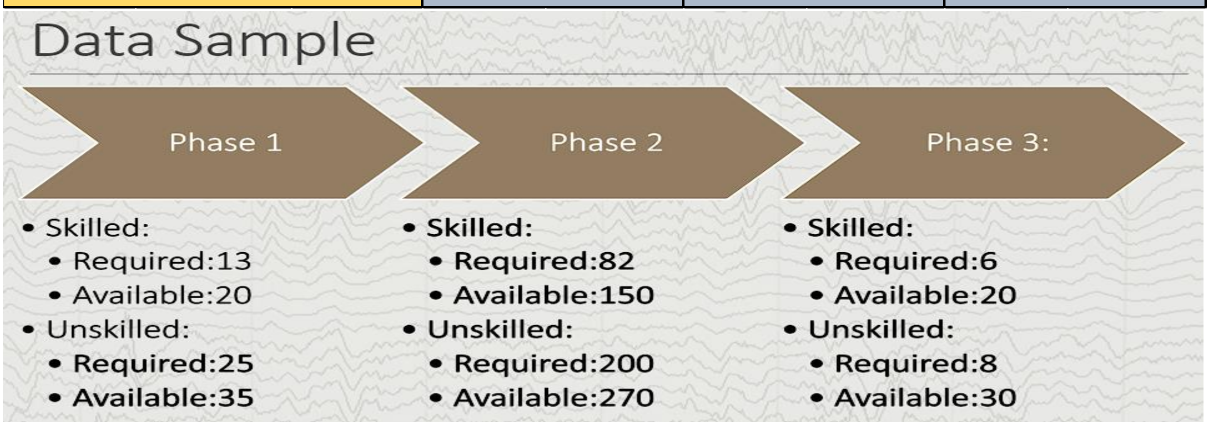


Fig 1. Data

3. PROBLEM DESCRIPTION

Objective/Value proposition: Reduction in labor cost can increase productivity and/or it can compensate against increasing transportation costs.[1] Sub-optimal scheduling increases an industry's tangible costs, not only through the consumption of a manager's time but also through over-allocation (Loss due to over-labor cost) and under-allocation of employees (Loss due to bad service).Thus, During different phases of the construction work, the labour requirements will differ and how ***to get the best utilization out of the available men hours to maximize the productivity and minimize the fraction overhead of construction project's total cost value allocated to labour management without hindering any regulations and adhering to every constraint***, is the basic aim of this project. Another objective is to provide a fair schedule in such a way that every workman would get enough working hours per week.

Subjected to:

- Daily minimum worker requirement per activity.
- Phase-wise worker availability.
- Binary assignment constraint
- Skill requirements.
- Maximum six days work stretch.
- 1 day off per week.
- 1 weekend (Sunday or Saturday) off per week.
- At-least one shift per week.

4. LITERATURE REVIEW

The people scheduling problem has been approached from many different angles by academics, from conventional optimization techniques to more contemporary machine learning and artificial intelligence techniques. The following common methods and strategies have been researched: Integer programming and linear programming, Heuristic Algorithms, Constraint programming, Local Search and Metaheuristics, Machine Learning and Artificial Intelligence and Software and Tools like 7shifts, Agendrix, MakeShift, Wrike, etc.It's important to note that the personnel scheduling problem can vary greatly depending on the specific context and industry. Whether it's healthcare, transportation, retail, or manufacturing, each domain presents its own unique challenges and constraints. The employee personnel scheduling problem was an interesting subject which motivated me to explore academic databases, journals, and conference proceedings which are briefed below:

Jumard, et. al. [4] proposed a 0 - 1 mixed-integer linear programmed (MIP) master problem to tackle the nurse tour scheduling problem. They used a diverse workforce that was based on nursing specializations or talents, overlapping shifts, and nurse preferences. The master problem featured a set of possible planning horizon adjustments that met all of the criteria. The master problem's purpose was to match nurses with each shift schedule. The master issue also included limitations such as a minimum number of nurses with skill level l planned at any one moment and a ratio of less experienced to more experienced nurses. To solve the master issue and maximize the nurses' preferences, a branch and bound strategy was used.

Love and Hoey [5] defined a mixed-integer linear program (MILP) for shift scheduling and tour-scheduling for a fast-food restaurant. They showed that a tour-scheduling problem can be solved with a minimum cost network flow. Their objectives were (1) Satisfy half-hourly personnel requirements with a minimum of surplus scheduled hours. (2) Give each employee the same number of workdays and work hours, with marginal workdays given to employees with better skill ratings. (3) Assign employees to work areas where they perform best. (4) Schedule each employee during his or her preferred work times as much as possible. The entry of employee availability data was accomplished using a seven-day half-hour matrix structure with free-form cursor movement and a single letter designator for the availability status. The system produced schedules that would require very little manual adjustment; excessive adjustment would defeat the purpose of computerization.

Easton and Rossin [7] examine the issue of staffing at a minimum cost while providing acceptable levels of service and employee satisfaction. The scheduling of a mixed workforce with an even distribution of over-staffing yielded consistent customer and employee satisfaction levels. Over-staffing provides higher customer satisfaction with better and more consistent service and higher employee satisfaction with the availability of more flexible work hours. They propose that in the service industry staffing at a minimum cost is not as important a factor as customer and employee satisfaction**.** The maintenance of high satisfaction levels retains customers and minimizes employee turnover.

Van Den Berg Y and Panton DM [2] analyzed the existing condition and network models for the final stage of employee scheduling problem i.e. shift assignment to days worked in the schedule. Results generated for a number of test problems demonstrated, first, that the network devised to search for continuous solutions produces these solutions in a high proportion of cases where such solutions are known to exist. Second, for more general problems, the algorithm was shown to be efficient in its ability to generate either continuous or rotating solutions.

Emmons and Burns days-off Scheduling [8] is concerned with an employee scheduling problem including various shifts and work centers, in which employees are classified into a hierarchy with downward substitutability. A higher-level employee may execute the tasks of a lower-level employee, but not vice versa. A higher category employee, on the other hand, is paid more than a lower category employee. The demand for each category at a specific work center during a given shift is fixed throughout the week and may change on weekends. Two goals must be met: the first is to find the lowest-cost workforce mix of employee categories required to meet specified demand requirements, and the second is to assign the selected employees to shifts and work centers based on their preferences for shifts, work centers, and off-days. A mixed-integer programming model is first built for the issue, and then a specialized scheduling heuristic is developed for it. Computational studies show that the suggested heuristic finds solutions that are within 92-99% of optimality for a variety of genuine test cases.

From this thorough literature review, I realized that there is a need for days-off scheduling along-with weekend-off scheduling in my problem since the personals are assigned to the job over a period of 28 days (i.e., 4 weeks) and follow continuing the pattern of rotation till the rest of the phase. After getting the output from days-off scheduling model, I would then have to schedule each employee based on an assignment problem using Big M for penalties.

5. FORMULATION OF THE PROBLEM

Indices used: i, j and k.

Sets used: X_{ij}, Y_{ij}, E_{ij}, G_i, H_{ij}, C_{ij}, a_j, b_j and F_{ij}.

Nomenclature: n $\rightarrow$number of unskilled labourers available per day per phase.

m $\rightarrow$number of skilled labourers available per day per phase.

n+m $\rightarrow$number of total labourers available per day per phase

d $\rightarrow$number of days involved in a shift rotation. (i.e., 28 in this case for 4 weeks).
a_j $\rightarrow$number of minimum unskilled labourers required per day per phase.
b_j $\rightarrow$number of minimum skilled labourers required per day per phase.

5.1Model 1 formulation: (based on Emmons and Burns days-off scheduling model)

Objective function: To reduce the minimum number of days-off that can be given to each labourer for a shift rotation of d days per phase.

Minimize $Z_1 = \sum_{i=1}^{n+m} \sum_{j=1}^{d} X_{ij}$; where d = 28; n = 35(Phase 1), 270(Phase 2), 30(Phase 3)

; m=20(Phase 1), 150(Phase 2), 20(Phase 3)

Subjected to:

1) X_{ij} is binary (X_{ij} ϵ {0,1})
   X_{ij} = 0; for schedulable days.
   = 1; for days off.
2) Minimum number of un-skilled labourers required per day per phase:

$$n - \sum_{i=1}^{n} X_{ij} \geq a_j; \forall j$$; where a_j =25(Phase 1), 200(Phase 2), 8(Phase 3)

3) Minimum number of skilled labourers required per day per phase:

$$m - \sum_{i=n+1}^{n+m} X_{ij} \geq b_j; \ldots, \forall j$$; where b_j = 13(Phase 1), 82(Phase 2), 6(Phase 3)

4) Maximum available un-skilled labourers per day per phase:

$$\sum_{i=1}^{n} X_{ij} \geq 0; \forall j \text{ [i.e., } n - \sum_{i=1}^{n} X_{ij} \leq n; \forall j \text{]}$$

5) Maximum available skilled labourers per day per phase:

$$\sum_{i=n+1}^{n+m} X_{ij} \geq 0; \ldots, \forall j \text{ [i.e., } m - \sum_{i=n+1}^{n+m} X_{ij} \leq m; \forall j \text{]}$$

6) Weekends off: at-least one weekend off (either Sunday or Saturday):

$$G_i = X_{i6} + X_{i7} + X_{i13} + X_{i14} + X_{i20} + X_{i21} + X_{i27} + X_{i28}$$

$$G_i \geq 2; \forall i .$$

7) At-least one day off per week:

$$Ei1 = \sum_{j=1}^{7} X_{ij} \ ; \ Ei2 = \sum_{j=8}^{14} X_{ij} \ ; \ Ei3 = \sum_{j=15}^{21} X_{ij} \ ; \ Ei4 = \sum_{j=22}^{28} X_{ij}$$

$Eik \geq 1; \forall i, \forall k$; where k = 1 to 4.

8) Maximum six days work stretch:

$$H_{i1} = \sum_{j=1}^{7} X_{ij} \;; H_{i2} = \sum_{j=2}^{8} X_{ij} \;; H_{i3} = \sum_{j=3}^{9} X_{ij} \;; H_{i4} = \sum_{j=4}^{10} X_{ij} \;; H_{i5} = \sum_{j=5}^{11} X_{ij} \;; H_{i6} = \sum_{j=6}^{12} X_{ij} \;;$$

$$H_{i7} = \sum_{j=7}^{13} X_{ij} \;; H_{i8} = \sum_{j=8}^{14} X_{ij} \;; H_{i9} = \sum_{j=9}^{15} X_{ij} \;; H_{i10} = \sum_{j=10}^{16} X_{ij} \;; H_{i11} = \sum_{j=11}^{17} X_{ij} \;; H_{i12} = \sum_{j=12}^{18} X_{ij} \;;$$

$$H_{i13} = \sum_{j=13}^{19} X_{ij} \;; H_{i14} = \sum_{j=14}^{20} X_{ij} \;; H_{i15} = \sum_{j=15}^{21} X_{ij} \;; H_{i16} = \sum_{j=16}^{22} X_{ij} \;; H_{i17} = \sum_{j=17}^{23} X_{ij} \;;$$

$$H_{i18} = \sum_{j=18}^{24} X_{ij} \;; H_{i19} = \sum_{j=19}^{25} X_{ij} \;; H_{i20} = \sum_{j=20}^{26} X_{ij} \;; H_{i21} = \sum_{j=21}^{27} X_{ij} \;; H_{i22} = \sum_{j=22}^{28} X_{ij} \;;$$

$$H_{i23} = \sum_{j=23}^{28} X_{ij} + X_{i1} ; H_{i24} = \sum_{j=24}^{28} X_{ij} + X_{i1} + X_{i2} ; H_{i25} = \sum_{j=25}^{28} X_{ij} + X_{i1} + X_{i2} + X_{i3} ;$$

$$H_{i26} = \sum_{j=26}^{28} X_{ij} + X_{i1} + X_{i2} + X_{i3} + X_{i4} ; H_{i27} = \sum_{j=27}^{28} X_{ij} + X_{i1} + X_{i2} + X_{i3} + X_{i4} + X_{i5} ;$$

$$H_{i28} = X_{i28} + X_{i1} + X_{i2} + X_{i3} + X_{i4} + X_{i5} + X_{i6}$$

$H_{ij} \geq 1; \forall i, \forall j$.

5.2 Model 2 formulation: (Assignment Problem to find the allocations of daily shifts)

Objective function: To optimize the total labour overhead per phase of our construction project.

Minimize $Z_2 = \sum_{i=1}^{n+m} \sum_{j=1}^{d} Y_{ij} * C_{ij}$; where C_{ij} is the cost matrix obtained by modifying the output of Model 1 i.e., X_{ij} .

Subjected to:

1) Y_{ij} is binary ($Y_{ij} \in \{0,1\}$)

   Y_{ij} = 0; if worker is not working.

   = 1; if worker is working.

2) Minimum requirement for skilled and un-skilled per day per phase:

$$\sum_{i=1}^{n} Y_{ij} = a_j ; \forall j \;; \sum_{i=n+1}^{n+m} Y_{ij} = b_j ; \forall j \;.$$

3) At-least one shift per labourer in a week:

$$F_{i1} = \sum_{j=1}^{7} Y_{ij} \;; F_{i2} = \sum_{j=8}^{14} Y_{ij} \;; F_{i3} = \sum_{j=15}^{21} Y_{ij} \;; F_{i4} = \sum_{j=22}^{28} Y_{ij} \;;$$

$F_{ik} \geq 1; \forall i, \forall k$.

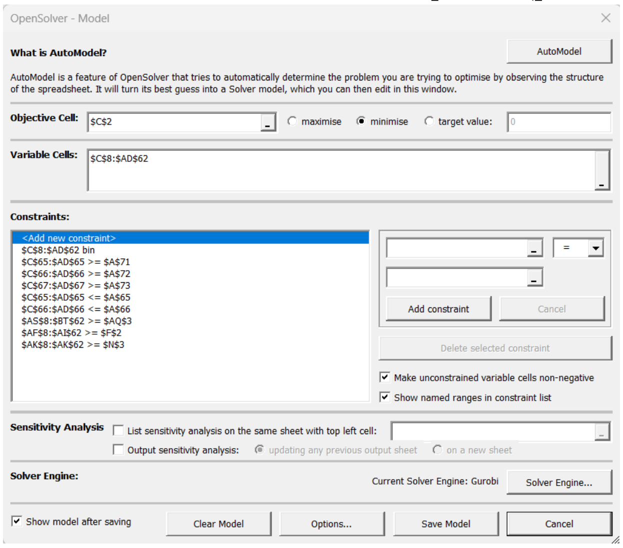
4) Availability Constraints: This can be taken care by cost matrix C_{ij} itself.

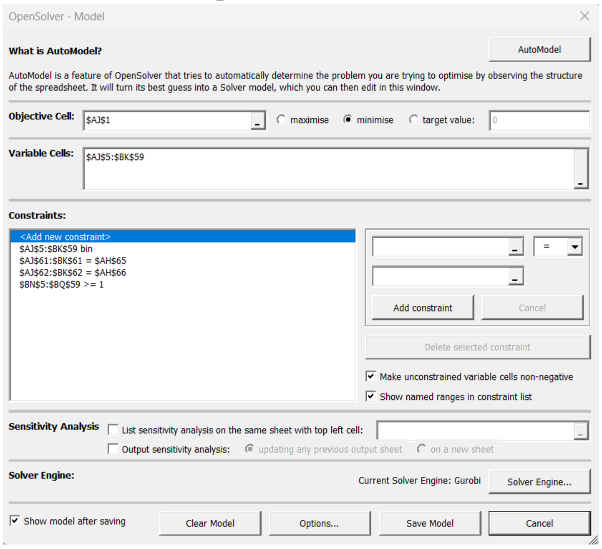
C_{ij} = 10000 for the day-offs and worker's unavailability.

= 144 CAD (i.e., 8hours per day * 18 CAD per hour) for un-skilled labourers.
= 176 CAD (i.e., 8hours per day * 22 CAD per hour) for skilled labourers.

6. METHODOLOGY

To begin with, I decided to formulate two models, one for days-off scheduling and the other for using the output of model 1 to produce a perfectly feasible day wise schedule for 4 weeks (i.e.,28 days) rotation for every available labourers for that particular phase. This 4-week schedule will be rotated for the rest of the phase. Both the models were created in Excel and by using Gurobi solver engine in Open-solver, initial solution was reached. Objective function and Constraints were established according to the algebraic model shown in 5.1 and 5.2. Later on, by adding or editing certain constraints or even by making some changes in the given data experiments were conducted to end up with a feasible and practically useful solution. Given below are some screenshots of models formulated in Excel along with the constraints; similar models were created for all three phases (please refer the excel file uploaded).





Model 1 Model 2

Fig 2. OpenSolver models with constraints

7. SOLUTION:

Phase 1(Model 1): Below figure shows the solution of Model 1(X_{ij}). Here, 1 day that are non-schedulable while 0 means the free to schedule shift.

Objective Days off	262

The objective value of 262 days suggests that we need to schedule the shift pattern in such a way that in the rotation period of 4 weeks (i.e., 4weeks * 7days a week * 55workers available =1540 available shift days) at-least 262 days will be needed to be scheduled off. Thus, leaving only 1540-262 =1278 workman-days as shift schedulable days for phase 1.

Type	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Skilled	36	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	37	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	38	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1
	39	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	40	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0
	41	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1
	42	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0
	43	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	44	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0
	45	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1
	46	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	47	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	48	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	49	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
	50	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1
	51	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	52	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	53	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	54	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
	55	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0

Type	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Un-skilled	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
	3	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0
	4	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
	5	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	6	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0
	7	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
	8	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0
	9	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
	10	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1
	11	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1
	12	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0
	13	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1
	14	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
	15	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1
	16	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
	17	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
	18	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0
	19	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0
	20	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
	21	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	22	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
	23	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0
	24	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	25	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
	26	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1
	27	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	28	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
	29	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
	30	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0
	31	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0
	32	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0
	33	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
	34	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1
	35	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0

Fig 3. Solution Model 1 Phase-1(Xij)

Phase 1(Model 2):

Input: C_{ij} Cost Matrix formulated by replacing 144 and 176 in place of 0s for Un-skilled and Skilled labourers respectively and 10000 as a big number to show penalty in place of 1s in the set X_{ij} . Below figure shows the cost matrix C_{ij} for phase 1:

Objective Function	164864

Type	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Skilled	36	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176
	37	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176
	38	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	10000	176	176	176	176	176	176	10000
	39	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000
	40	176	176	176	176	10000	176	10000	176	176	176	176	176	176	10000	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176
	41	176	176	176	10000	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	10000	176	176	176	176	176	176	10000
	42	176	176	176	176	10000	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	10000	176	176	176	176	176	176	10000	176
	43	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176
	44	176	176	176	176	176	10000	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	10000	176
	45	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	10000	176	176	176	176	176	176	10000
	46	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000
	47	176	176	10000	176	176	176	10000	176	176	176	176	176	10000	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176
	48	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000
	49	176	10000	176	176	176	176	10000	176	176	176	176	176	176	10000	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176
	50	176	176	176	176	176	10000	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	10000
	51	176	176	10000	176	176	176	10000	176	176	176	176	176	176	10000	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176
	52	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176
	53	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176	176	176	176	176	176	10000	176
	54	176	10000	176	176	176	176	176	176	10000	176	176	176	176	10000	176	176	176	176	176	176	10000	176	10000	176	176	176	176	176
	55	10000	176	176	176	176	176	176	10000	176	176	176	176	10000	176	176	176	176	176	176	10000	176	10000	176	176	176	176	176	176

Type	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Un-skilled	1	10000	144	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144
	2	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144
	3	144	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144
	4	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144
	5	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144
	6	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	10000	144
	7	144	10000	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144
	8	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	10000	144	144	144	10000	144	144	144	144	144	144	10000	144
	9	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	10000	144	144	144	10000	144	144	144	144	144	144
	10	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000
	11	144	144	144	144	144	10000	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000
	12	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	10000	144
	13	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	10000
	14	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144
	15	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000
	16	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144
	17	10000	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	144
	18	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	10000	144
	19	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144
	20	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	10000
	21	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000
	22	144	144	10000	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144
	23	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144	10000	144
	24	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000
	25	10000	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144
	26	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000
	27	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000
	28	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144	144	144	10000	144	144	144
	29	144	10000	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144
	30	144	10000	144	144	144	144	144	144	10000	144	144	144	144	10000	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144
	31	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	10000	144
	32	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	10000	144	144	144	144	144	144	10000	144
	33	144	144	144	10000	144	144	144	144	144	144	10000	144	144	10000	144	144	144	144	144	144	10000	144	144	144	10000	144	144	144
	34	144	144	144	144	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144	10000	144	10000	144	144	144	144	144	144	10000
	35	10000	144	144	144	144	144	10000	144	144	144	144	144	144	10000	10000	144	144	144	144	144	144	10000	144	144	144	144	144	144

Fig 4. Cost Matrix Model 2 Phase-2 (Cij)

The objective value of 164,864 CAD represents the optimal total labour cost for every 4 weeks of rotation period of phase 1 after considering all the constraints mentioned above. Similarly, both the models for phase 2 and phase 3 were also operated to get the optimal values of 1,210,496 CAD and 61,824 CAD respectively. Thus, the total labour overhead for the whole construction project turns out to be: (164,864*6) + (1,210,496*16) + (61,824*2) = 20,480,768 CAD. Below figures show the final solution indicating the shifts schedule for each available labourer for phase 1.

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1
	2	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1
	3	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	0	1	1	1	1	0	0	1	1	1
	4	0	1	1	0	1	0	1	1	1	1	0	1	0	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1
	5	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	0	0	1
	6	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	1	1	1	1	1	0	1
	7	1	0	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	1	1
	8	1	1	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	1	0	0	1
	9	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1
	10	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	0
	11	1	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0
	12	1	1	1	0	1	0	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	0	1	1	1	1	0	1
	13	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	0
	14	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	1	0	0	0	1
	15	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	1	1	0
	16	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	0	1	1	1	0	0	1	1	1	1
	17	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1
Unskilled	18	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	0	0	1
	19	0	1	1	1	0	1	0	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	0	1	0	1	1	1
	20	1	1	1	1	1	1	0	0	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	0
	21	1	0	0	1	0	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	0
	22	1	1	0	1	0	1	1	0	1	1	1	0	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	1
	23	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1
	24	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	1	0	0	1	1	0
	25	0	1	1	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1
	26	1	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	0
	27	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	0	1	1	1	1	1	0
	28	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1
	29	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1
	30	1	0	1	1	0	1	1	1	0	1	1	0	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1
	31	0	0	1	1	0	1	1	0	0	1	1	0	1	1	0	0	1	1	0	1	0	1	0	1	0	0	0	1
	32	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	0	1	0	0	1	0	1	0	1	1	0	1
	33	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	1
	34	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	0	1	1	0
	35	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	1	1	0	0	1	1

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
	36	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1
	37	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1
	38	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	1	0	1	1	0	1	0	0	0	1	1	0
	39	0	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0
	40	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	41	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	0	1	1	1	1	0	1	0
	42	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	0	1
	43	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
	44	1	1	0	1	0	0	1	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	0	1	0	0	1
Skilled	45	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	0	1	0	1	0	1	1	0
	46	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0
	47	1	1	0	1	1	1	0	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
	48	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0
	49	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	1	0	0	0	0	1	1
	50	1	1	1	1	0	0	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	0
	51	1	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	0	0	0	1	1	1	0	0	0	0	1	1
	52	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
	53	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1
	54	0	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1
	55	0	0	1	0	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	1	1

Fig 5. Final Solution Phase 1 (Yij)

Similarly, for phase 2 and phase 3, the same type of scheduled shift pattern is generated which is in the Excel file, hence fulfilling the objective of my project.

8. EXPERIMENTS

Numerous experiments were performed on this model giving fruitful and practically feasible responses, thus checking the robustness of my model.

8.1 Experiment 1: *Considering Sunday and Saturday together as a weekend*:

Below shown figure represents the extra constraints needed to consider Saturday and Sunday as one weekend together:

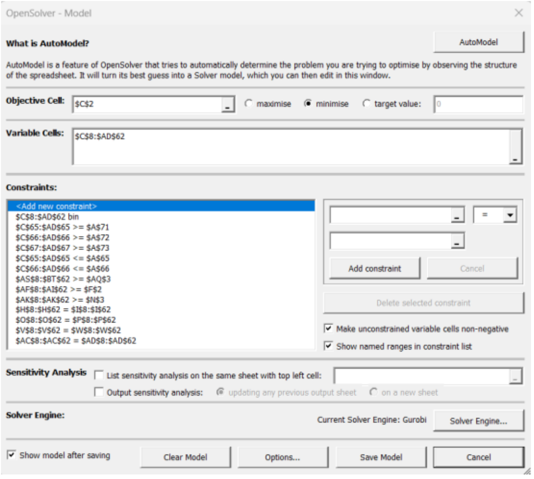


Fig 6. OpenSolver Model Exp1

Additional constraints needed for this experiment: $X_{i6} = X_{i7}$; $X_{i13} = X_{i14}$; $X_{i20} = X_{i21}$; $X_{i27} = X_{i28}$ in the first model.

<u>Solution</u>: *Phase 1(Similar process for phase 2 and 3 as well) refer Exp1.xls.*

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Skilled	36	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1
	37	0	1	0	1	1	0	0	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1
	38	1	1	0	0	0	0	0	1	1	0	0	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	1	1
	39	0	1	1	0	1	0	0	0	1	1	0	1	0	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1
	40	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0
	41	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1
	42	1	1	1	0	1	1	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0
	43	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	0	0	1	0	1	1	1	1	1
	44	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	0	0
	45	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	0	0	0	1	1	0	1	1	1
	46	1	0	0	1	1	1	1	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0
	47	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	0	0	1	1	0	1	0	1	1
	48	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	49	1	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1
	50	1	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	51	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1
	52	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0
	53	0	1	0	1	1	0	0	0	1	0	1	1	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1
	54	0	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0
	55	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	0	0	0

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Unskilled	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	2	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0
	3	1	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	4	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0
	5	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	6	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	7	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	8	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	9	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
	10	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1
	11	1	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1
	12	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	13	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1
	14	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	1
	15	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1
	16	1	1	0	0	1	0	0	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1
	17	1	1	1	0	0	1	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	0	1	1	1
	18	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	0	0	1	1	0	1	0	1	1
	19	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1	0	0
	20	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	0
	21	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	1	0	0
	22	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	1	0	1	1
	23	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	0	0
	24	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	1	0	1	1	1	1
	25	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	0
	26	1	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	0	1	0	0	1	1
	27	1	0	0	1	1	1	1	1	0	0	1	1	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	0
	28	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	1	1	1	0	1	1	0	0
	29	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1
	30	1	0	1	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	1	1	1
	31	1	0	1	0	1	1	1	1	0	1	0	1	0	0	1	0	1	0	1	1	0	1	0	1	0	0	0	1
	32	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	0	1	1	0	0	1	0	1
	33	1	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	0	0	1	1
	34	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	0	1	1	0	1	1	1	0
	35	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	0	0	1	1	0	0	0	1	1

Fig 7. Solution of Exp1

8.2 Experiment 2: *Changes in the number of minimum labourers required per day:*
This model showed its validity by giving a feasible output even by changing the minimum number of labourers required per day.

Solution: Here, changes in labourers required will result in changes in the outputs and objective values of both the models. The new objective values of all three phases were verified. It was also noted that increasing the number of minimum workers worked as fine as decreasing it. Below given figure shows the solution obtained form this experiment for phase 1. (Experiments for phase 2 and 3 can be done the same way *refer Exp2.xls*)

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Unskilled	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1
	2	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0	1	1	1	1	1	1	0	1
	3	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	0
	4	1	1	0	1	1	0	1	1	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1
	5	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1
	6	0	1	1	0	1	1	0	1	1	1	0	1	1	0	0	1	0	0	1	1	1	0	0	1	1	1	1	1
	7	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1
	8	0	0	1	1	0	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1
	9	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0
	10	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	0	1
	11	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	0	0	1	1	1	0
	12	1	0	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	0
	13	0	0	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	1	1	1	0	1	0	1	0	0	1	1
	14	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	1	1	0	0	1
	15	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0
	16	1	1	0	1	0	0	1	1	0	0	1	0	1	1	1	0	0	1	0	1	1	1	0	0	1	1	0	1
	17	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1
	18	1	1	1	1	0	1	1	0	1	1	1	0	1	0	1	1	1	1	0	1	0	0	0	1	1	0	1	1
	19	1	1	0	1	0	1	1	0	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	0	0	1	1	1
	20	0	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1
	21	1	0	0	1	0	0	1	1	0	0	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1
	22	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	0	0	0	1	0	1
	23	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0
	24	1	0	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	0	1	0	0	1	0	1
	25	0	1	1	0	0	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	1	1
	26	1	1	1	0	1	0	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1	1	0	1	1	1	0	1
	27	1	0	0	1	1	1	0	1	0	0	1	1	1	0	1	0	0	1	1	1	1	0	1	0	1	1	1	1
	28	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	0	1	1	1	0	1	1	0
	29	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0
	30	1	0	0	1	0	0	1	1	0	1	1	0	0	1	1	0	0	1	0	1	1	1	1	0	1	1	1	1
	31	0	0	1	1	1	1	0	1	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	0	1	0
	32	0	1	0	1	1	1	0	0	1	0	1	1	0	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1
	33	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	0
	34	0	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1
	35	0	0	1	1	0	1	1	0	0	1	1	0	0	1	0	0	1	1	1	0	1	1	1	1	0	0	1	1

Yij	Week>	1							2							3							4						
	Day>	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S	M	T	W	R	F	s	S
Skilled	36	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	0
	37	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0
	38	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
	39	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0
	40	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1	1	1
	41	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1	1	0	1	0
	42	1	1	1	1	1	0	1	0	1	1	1	1	0	1	0	0	1	1	1	1	1	0	1	1	1	1	0	1
	43	1	0	0	1	1	1	1	1	0	0	1	1	1	0	1	1	0	1	1	0	1	1	0	0	1	1	1	1
	44	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
	45	0	1	0	1	0	1	0	1	1	0	1	0	1	0	1	1	0	1	0	1	1	1	1	0	0	0	1	1
	46	0	0	1	1	1	0	1	0	1	1	1	1	0	1	0	1	1	1	1	0	1	0	0	1	1	1	0	1
	47	0	1	0	1	1	0	1	1	1	0	0	1	0	1	1	1	0	1	0	1	1	1	1	0	0	1	1	1
	48	0	1	1	0	0	1	1	0	1	1	0	0	1	0	0	1	1	1	1	1	0	0	1	1	0	0	1	1
	49	0	0	1	0	0	1	1	0	0	1	0	0	1	1	0	0	1	0	0	0	1	1	0	1	0	0	0	1
	50	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	0
	51	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	0	1	1	1	0	1
	52	1	1	0	1	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1
	53	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	1	1	1	0	1	0	1
	54	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1
	55	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1	0

Fig 8. Solution of Exp2

8.3 Experiment 3:

Changes in per hour wages: Considering 10 percent hike in hourly labour wages after every 4 months from the start (refer Exp3.xls)

Here, I have replaced the 1s of Xij obtained after running model 1 by the following values.

Hike	Months		1 to 6	7 to 12	13 to 18	19 to 24
10 percentage every 6 months	daily wages	Un-skilled	144	158.4	174.24	191.664
		Skilled	176	193.6	212.96	234.256

Here, the Yijs remain the same as before but the objective value for model 2 changes, as it represents the total labour cost for the rotation period.

To conclude, I have made significant changes to check the robustness of my model and all of them gave optimal solutions.

9. CONCLUSION AND FUTURE SCOPE

The feasible solution obtained from this project was found to be satisfactory and practically usable. By performing some experiments, the validity of my model was also checked. Though, this study was limited to laborers working in the construction project, it can be extended to other types of scheduling as well like Industry workers, housekeeping staff, Hotel/Restaurant staff and many more. This model can be made complicated by the addition of constraints like personal availability, regional holidays, alternative weekends off per rotation, etc. We can easily schedule off the holidays and personal un-availabilities from the shift pattern by placing a penalty value (10000) in the cost matrix. This model can also be re-formulated, by following the same algorithms mentioned in the project, to schedule a 10 weeks or 5 weeks rotation pattern. As an extension of this model, we can also schedule hierarchical workers in which one type of workers can be substituted by another type but with certain limitations. Similarly, we can also consider that 1 skilled worker can do the task for 5 un-skilled labourers and can schedule them likewise. As an experiment, the values of a_j and b_j can be considered different for all 28 days, which will basically the practical case.

9. REFERENCE

[1] Ağralı S, Taşkın ZC, Ünal AT. Employee scheduling in service industries with flexible employee availability and demand. Omega. 2017 Jan 1;66:159-69.

[2] Van Den Berg Y, Panton DM. Personnel shift assignment: existence conditions and network models. Networks. 1994 Oct;24(7):385-94.

[3] Kasirzadeh A, Saddoune M, Soumis F. Airline crew scheduling: models, algorithms, and data sets. EURO Journal on Transportation and Logistics. 2017 Jun 1;6(2):111-37.

[4] Jaumard, B., F. Semet, & Vovor, T. A generalized linear programming model for nurse scheduling. European Journal of Operational Research. 1998 107(1), 1–18.

[5] Love, R. & Hoey, J. Management science improves fast food operations. Interfaces, 1990 20(2), 21–29.

[6] Mohan S. Scheduling part-time personnel with availability restrictions and preferences to maximize employee satisfaction. Mathematical and Computer Modelling. 2008 Dec 1;48(11-12):1806-13.

[7] F. Easton, D. Rossin, Overtime schedules for full-time service workers, Omega 25 (1997) 285–299.

[8] Emmons and Burns days off scheduling.

[9] https://www.payscale.com/research/CA/Job=Construction_Laborer/Hourly_Rate

[10]https://www.capterra.com/sem-compare/employee-scheduling-software/?utm_source=ps-google&utm_medium=ppc&v=pvp_wci_a&utm_campaign=:1:CAP:2:COM:3:All:4:INTL:5:BAU:6:SOF:7:Desktop:8:BR:9:Employee_Scheduling&network=g&gclid=CjwKCAjw8symBhAqEiwAaTA__C0VVhKbR4OW0Zud_BjtgxLIn9J2cRA-_XNp3Y9LotYIy7MT4uY4GxoC8UcQAvD_BwE

[11] Davis, Randall, and Douglas B. Lenat. Knowledge-Based Systems in Artificial Intelligence: 2 Case Studies. McGraw-Hill, Inc., 1982.

[12] Krajewski, Lee J., Larry P. Ritzman, and Phil McKenzie. "Shift scheduling in banking operations: A case application." Interfaces 10.2 (1980): 1-8.