GUROBI OPTIMIZATION

Optimization Application Demo

Workforce Scheduling

Introduction

The operations research (OR) community has extensively studied workforce planning under the topic of manpower and personnel planning. The general problem of manpower planning, as Gass (1991) defines it, involves determining the number of workers and their skills that best meet an organization's future operational requirements. Applications in the service sector include shift scheduling (Burns and Koop 1987) , nurse rostering (Kao and Queyranne 1985) , and crew scheduling in the airline (Barnhart et al.) (Yu et al. 2004) and railway (Abbink et al. 2005) industries.

Studies on optimizing project staffing can be found for managing service projects in the context of a service center (Valls et al. 2009) and IT project staffing (Li and Womer 2009a) . In both settings, operational level personnel assignment and task-sequencing and scheduling decisions are simultaneously optimized in the framework of resource-constrained project-scheduling problems (cf. Demeulemeester and Herroelen 2002) .

People are the most important asset in the services industry and they represent the largest cost. Workforce allocation and personnel scheduling deal with the arrangement of work schedules and the assignment of personnel shifts to cover the demand for resources that vary over time. These problems are very important in service industries such as:

- Call centers operations
- Hospitals
- Police departments
- Transportation (plane crews, bus drivers)
- Hospitality
- Restaurants

Workforce Scheduling Problem

Consider a service business, like a restaurant, that develops its workforce plans for the next two weeks, considering a typical seven-day week. The service requires only one set of skills. There are a number of workers with the same set of skills and with identical productivity that are available to work on some of the days during the two-week planning horizon. There is only one shift per workday. Each shift may have different resource (workers) requirements on each workday.

The service business may hire extra (temp) workers from an agency to satisfy shift requirements. The service business wants to minimize the number of extra workers they need to hire and as a secondary objective (fairness), it wants to balance the workload of employed workers.

Solution Approach

This workforce scheduling problem is modeled as a MIP (Mixed Integer Programming) problem with multiple objective functions. We use a hierarchical approach to tackle this multi-objective optimization problem. This approach assigns a priority to each objective and optimizes for the objectives in decreasing priority order. At each step, it finds the best solution for the current objective, but only from among those that would not degrade the solution quality for higher priority objectives.

The hierarchical approach won't allow later objectives to degrade earlier objectives. For example, consider an optimization problem with two objectives- the highest priority objective is the primary objective, and the lower priority objective is the secondary objective. Assume a MIP problem that is feasible, then the hierarchical approach finds the optimal value of the primary objective. The hierarchical approach adds a constraint where the primary objective must be equal to the optimal value just found. Then, the approach will optimize the MIP problem with respect to the secondary objective, considering the added constraint. This behavior can be relaxed for MIPs through a relative tolerance. By setting a relative tolerance for the primary objective, you can indicate that the secondary objective can degrade the primary objective by the specified relative amount. For instance, assume we have two minimization objectives. If the minimum value for the primary objective is 100, and if we set the relative tolerance for this objective to 20%, then the second optimization step would find the best solution for the secondary objective from among all solutions with the primary objective value in the range of [100, 120].

The primary objective of the workforce scheduling problem is to minimize the number of extra workers required to satisfy shift requirements, and the secondary objective is to balance the workload among employed workers. For the secondary objective, we minimize the maximum difference in the number of shifts worked between any pair of workers.

Example Of The Workforce Scheduling Problem

To ground the ideas behind the workforce scheduling problem, let's consider the following example described in figure 1.

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Figure 1: Employed worker availability.

In this example, we have eight employed workers. The planning horizon is of 14 days, starting on Mon1 and ending on Sun14. The green cells in figure 1 represent the availability of each employed worker during each day of the planning horizon.

There is only one shift for each day of the planning horizon. The shift requirements are described in figure 2.

Requirements

Shift	Reqirement
Mon1	4
Tue2	2
Wed3	4
Thu4	4
Fri5	5
Sat6	6
Sun7	5
Mon8	2
Tue9	2
Wed10	3

The shift requirements represent the number of workers required at each shift.

Key Assumptions For This Demo

- Single shift per day
- Two (7-days) week planning horizon
- The workers only have one role
- All resources are identical, require same skill set, same productivity and experience
- No rotation for working on the weekends
- The primary objective is to minimize the number of extra temporary workers required to satisfy shift requirements and the secondary objective is to balance workload of employed workers
- Inability to hire new, non-temporary workers
- Labor law and business rules are not considered

Optimization

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LOG OPTIMIZE

Optimization Application Demo

Workforce Scheduling

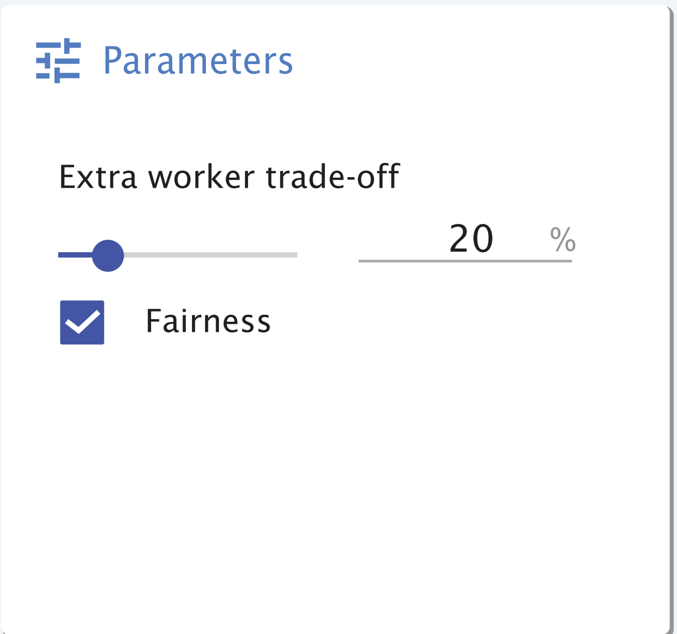


Figure 3: Control parameters of the optimization engine.

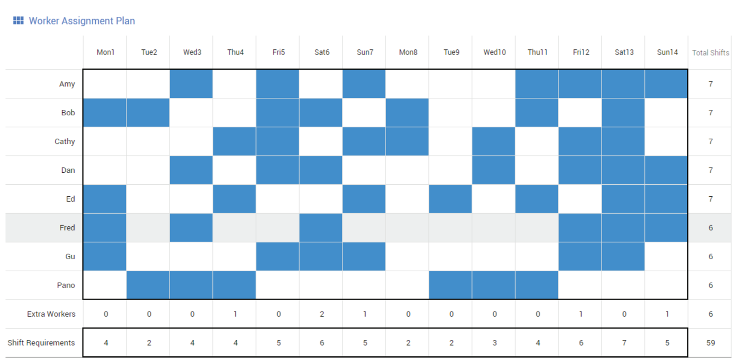
Output reports

For the workforce scheduling demo, it is important to understand which employed worker is allocated to each workday-shift. Also, we need to understand how many extra workers we need to have at each workday-shift in order to satisfy shift requirements.

Consider the example described in the problem description section.

In figure 3, we have the button that will run the optimization engine. In addition, we have the optimization parameters. Recall that the primary objective is to minimize the number of extra workers required to satisfy shift requirements and the secondary objective is to balance the workload among the employed workers - we called this secondary objective the fairness objective. The extra worker trade-off is the value of the relative tolerance that the user wants to use in order to maximize fairness while relaxing the optimal value of the primary objective. For example, assume the minimum value of extra workers required is 10, and the user defines the extra worker trade-off to be 20%, it means that the optimization engine will try to maximize fairness considering up to 12 extra workers. In addition, the fairness secondary objective can be disabled, and in this case the optimization engine will optimize only the primary objective.

In figure 4, we have an output report describing which employed worker is assigned to each workday-shift. The assignments are represented by the blue cells.



Worker Assignment Plan

	Mon1	Tue2	Wed3	Thu4	Fri5	Sat6	Sun7	Mon8	Tue9	Wed10	Thu11	Fri12	Sat13	Sun14	Total Shifts
Amy															7
Bob															7
Cathy															7
Dan															7
Ed															7
Fred															6
Gu															6
Pano															6
Extra Workers	0	0	0	1	0	2	1	0	0	0	0	1	0	1	6
Shift Requirements	4	2	4	4	5	6	5	2	2	3	4	6	7	5	59

Figure 4: Employed worker assignment.

The "Extra workers" row represents the number of extra workers required at each workday to satisfy demand. The "Shift requirements" row represents the number of workers required at each workday. The column "Total shifts" represents the number of shifts that each employed worker will work. The cell in this column for extra workers represents the number of shifts that extra workers will work, 6 in this example. The last cell in this column represents the total number of shifts that employed and extra workers will work, which is 59. This number is equal to the total number of shift requirements.

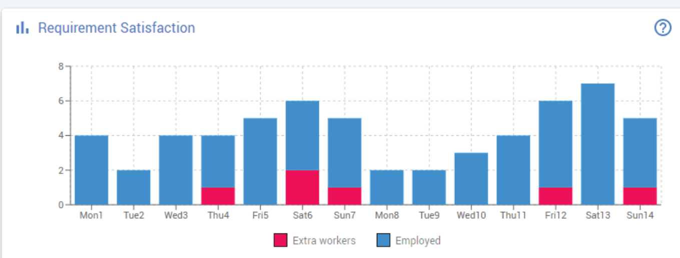


Figure 5. Shift allocation and employed/extra worker allocation.

In figure 5, we show the distribution of the number of shifts allocated to each employed worker. We also show the number of employed and extra workers allocated at each workday.

Conclusion

The paper provides an overview of the Gurobi Optimization Application Demo by illustrating one related to a workforce scheduling problem. As discussed, this type of problem is very important in services industries.

The workforce scheduling problem is modeled as a MIP with multiple objective functions. The primary objective of the workforce scheduling problem is to minimize the number of extra workers required to satisfy shift requirements, and the secondary objective (fairness) is to balance the workload among employed workers. For the secondary objective, we minimize the maximum difference in the number of shifts worked between any pair of workers.

A solution of the workforce scheduling problem is an assignment of the employed workers to each day of the two week planning horizon, to satisfy the shift requirements. If not enough employed workers are available at a day during the planning horizon, extra workers are temporarily hired. To understand the fairness of the assignment, an output report is displayed showing the number of shifts an employee works during the two week planning horizon.

References

[1] Santos et al.: HP Enterprise Services Uses Optimization for Resource Planning. Interfaces pp 1-17.

[2] Gass, S. I. 1991. Military manpower planning models. Comp. Oper. Res. 18(1) 65–73

[3] Burns, R. N., G. J. Koop. 1987. A modular approach to optimal multiple-shift manpower scheduling. Oper. Res. 35(1) 100–110

[4] Kao, E. P. C., M. Queyranne. 1985. Budgeting costs of nursing in a hospital. Management Sci. 31(5) 608–621

[5] Barnhart, C., A. Cohn, E. L. Johnson, D. Klabjan, G. L. Nemhauser, P. Vance. 2002. Airline crew scheduling. R. W. Hall, ed. Handbook in Transportation Science. Kluwer Academic Publishers, Norwell, MA, 517–560

[6] Yu, G., J. Pachon, B. Thengvall, D. Chandler, A. Wilson. 2004. Optimizing pilot planning and training for Continental Airlines. Interfaces 34(4) 253–264.

[7] Abbink, E., M. Fischetti, L. Kroon, G. Timmer, M. Vromans. 2005. Reinventing crew scheduling at Netherlands Railways. Interfaces 35(5) 393–401.

[8] Valls, V., A. Perez, S. Quintanilla. 2009. Skilled workforce scheduling in service centers. Eur. J. Oper. Res. 193(3) 791–804.

[9] Li, H., K. Womer. 2009a. Scheduling projects with multi-skilled personnel by a hybrid MILP/CP Benders decomposition algorithm. J. Scheduling 12(3) 281–298.

[10] Demeulemeester, E. L., W. S. Herroelen. 2002. Project Scheduling: A Research Handbook. Kluwer Academic Publishers, Dordrecht, The Netherlands.