Chapter 9

Summary and outlook

In this work, we have outlined a hierarchical planning approach to solve three problems that arise in many firms at the interface of multi-project management and human resource management. The problem at the top level is a static project selection problem. The goal of this problem is to determine a project portfolio of maximum benefit that complies with the availabilities and the skills of a given workforce. At the second level, a project team must be composed for each selected project such that all skill requirements of a project can be accomplished by the respective team. The goal of this workforce assignment problem is to minimize average team size. At the bottom level, a utilization leveling problem is considered; after workload of all selected projects has been allocated to workers, departmental workload must be distributed among the workers of each department such that the working times of employees within a department are leveled. Finding good solutions to these problems has great impact on the success of a firm and on the well-being of its employees.

For all three problems, we have formulated mathematical optimization models and analyzed problem complexity. We have proved that the project selection problem and the workforce assignment problem are NP-hard in the strong sense and have shown that the utilization leveling problem can be solved in polynomial time by a specially tailored leveling algorithm. For the project selection problem, we examined the impact that the degree of multi-skilling has on portfolio benefit and found diminishing marginal returns of multi-skilling. Furthermore, we compared different skill configurations for a constant degree of multi-skilling. The tested configurations included alternative chaining strategies. A strategy that features diverse chains performed best; its superiority was verified by established flexibility measures and by a new one. The MIP solver of CPLEX could provide solutions of acceptable quality in reasonable time even for large-sized instances of the project selection problem. For the workforce assignment problem, however, the exact branch-and-cut method of CPLEX performed much worse, even though we tightened the model formulation by globally valid inequalities.

In order to determine solutions for large-sized instances of the workforce assignment problem in acceptable time, we have devised four construction heuristics: a greedy randomized assignment procedure (GRAP), an iterated simultaneous assignment procedure (ISAP), a drop method (DROP), and a rounding heuristic (ROUND). These heuristics have been embedded in a multi-start approach and were thoroughly tested in a comprehensive numerical analysis. For this analysis, an instance generator was devised to create artificial test instances systematically. The heuristic DROP performed best against the test instances and is recommended because it guarantees to find a feasible solution if any exists and because it strikes a good balance between solution time and quality. For

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solving subproblems within DROP, we compared the dual simplex method of CPLEX to our implementation of the generalized network simplex method. Here, the LP solver of CPLEX performed better.

Our work has made four novel contributions. First of all, we have provided methods to assemble small project teams of multi-skilled workers with heterogeneous skill levels. The importance of forming small teams has been emphasized in the literature for more than three decades but an approach to this team formation task in a multi-project environment where skill levels of workers are distinguished has been lacking so far. Second, we have outlined detailed pseudo code for implementing the generalized network simplex method. Up to now, textbooks have only sketched the underlying operations.

The other two contributions concern the project selection problem. We analyzed the impact of different skill configurations on portfolio benefit. In particular, we compared a classical skill chaining strategy to an alternative skill chaining strategy, which features diverse chains. Our numerical analysis has shown that the latter strategy is superior. So, our third contribution is the finding that a workforce which exhibits diverse skill chains is highly flexible. The fourth contribution is related to the way how we compared and assessed skill configurations. We used several flexibility measures to assess the quality of skill configurations. One of these measures was newly defined. It is based on a measure of Iravani et al. (2005). Like their measure, our new measure is very lean because it does not require information about the magnitude of skill requirements and about availabilities of workers. However, our new measure has higher discriminatory power than their measure and can serve as a valuable supplementation of their measure.

Especially the workforce assignment problem offers interesting areas for future work. With regard to the tested solution methods, the results of our performance analysis have shown that there is room for improvement. This holds for the exact approach with CPLEX as well as for the heuristics. Our future research will be directed at a genetic algorithm and at an advanced add method. We plan to integrate the genetic algorithm with GRAP or ISAP. Our aim is to combine the speed of these two construction heuristics with the learning strategy of an evolutionary improvement heuristic. For the advanced add method, we plan to follow ideas of Li and Womer (2009a,b) and think of a two-stage decomposition approach. At the first stage, small project teams are formed such that the joint skill set of each team covers all skills required by the corresponding project and such that the number of assignments is leveled across workers. The workload of projects, availabilities of workers, and skill levels are neglected at this stage. At the second stage, a linear program checks whether a feasible allocation of workload exists given the first-stage team assignments. For this check, the objective function of the linear program minimizes the amount of uncovered project workload. If uncovered workload remains, the project with the greatest amount of uncovered workload is identified and for this project an additional worker is demanded in the first-stage problem.

Another avenue for future research emanates from the fact that our hierarchical planning approach has considered only the deterministic case so far. We assumed the absence of uncertainty about data. Though, parameter values that are required for the models can often be estimated only roughly. Then, a robust optimization approach is of interest for risk-adverse decision makers.

A robust approach to our project selection problem should hedge against estimation errors with respect to project benefits and with respect to capacity demand and supply.

If it is not possible to obtain reliable point estimates for the benefit parameters b_p of each project $p \in \mathcal{P}$, the portfolio selection approach of Liesiö et al. (2007), which allows range estimates for parameters, can be a starting point for a modified approach. If skill requirements of projects and availabilities of workers are uncertain, it may be helpful to plan with capacity buffers, e.g., by increasing each skill requirement r_{pst} by a certain percentage.

A robust approach to the workforce assignment problem should at least partially hedge against the absence or departure of a worker. A partial hedge could mean that each skill required by a project is mastered by at least two members of the project team or by even more—depending on the size of the skill requirement.

Multi-objective approaches can be another rewarding area of future work, as we have already indicated in the discussion in Chapter 8. Managers that decide about the project portfolio for the upcoming year may not only seek for a portfolio of maximum benefit but may also wish to level the utilization of the workforce across the months in order to facilitate smooth operations. For the workforce assignment problem, it seems interesting to consider the strategic development of skills of workers as an additional goal, as it has been done by Gutjahr et al. (2008, 2010), Certa et al. (2009), and Süer and Tummaluri (2008), for example. The interesting point is that the goal of a flexible workforce where each worker masters several skills and where the skill levels of each worker are balanced and the goal of small teams have synergies because workers in small teams have greater opportunities to apply all their skills than workers in large teams.

For the inclusion of additional goals into our approach, it may also be beneficial to seize ideas from the works of Lai and Xue (1999), Lopes et al. (2008), Yoshimura et al. (2006), Doerner et al. (2004), Graves and Ringuest (2003), Gutjahr et al. (2008, 2010), Taylor et al. (1982), Valls et al. (2009), Corominas et al. (2005), Eiselt and Marianov (2008), and Certa et al. (2009), whose models feature either multiple objective functions or an objective function that is a weighted sum of multiple objectives. These works can provide inspiration for additional relevant objectives and for suitable solution techniques.

Finally, we want to suggest two further fields of future research. The first field is the integration of scheduling decisions into our hierarchical planning approach. If it is possible to postpone the start times of projects or even of work packages, the outcomes of our approach can be improved by exploiting this degree of freedom. The second field comprises the consideration of more flexible working time regimes that are common in many firms and the consideration of related aspects that are relevant in practice. If, for example, vacation entitlements of workers must be regarded, the concept of partially renewable resources may be helpful for modeling this practice-oriented aspect (cf. Böttcher et al., 1999; Salewski, 1999; Schirmer and Drexl, 2001). Frequently, working time regimes include arrangements that allow for extra hours or for unbalanced monthly hours worked as long as the hours worked during a whole year match the number of contracted hours. In Subsection 4.3.2, we have shown how both arrangements can be represented by constraints in a MIP model. However, in case of the latter arrangement, where hours worked can vary from month to month, only two of our heuristics for the workforce assignment problem, namely, DROP and ROUND, can exploit this flexibility. Though, the temporal decomposition of DROP would no longer be applicable and solution times of DROP would increase considerably. Hence, the development of fast and reliable heuristics that can exploit flexible working times would be another path for future work. Exploiting flexible working times would allow to select even better portfolios and to form even smaller teams.