Rostering-integrated Services and Crew Efficiency

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Abstract. Tourism is a service-intensive industry that is characterized by a highly competitive market. The adequate utilization of personnel provides the key means of tackling two conflicting tendencies: on the one hand, the consumers’ expections of a certain level of service quality; on the other, the expense usually associated with qualified human labor. Our paper presents (1) how the quality level of services can be augmented and (2) how the workforce can be used efficiently by extending a basic model through adequate constraints. All of the proposed supplementary services do not require additional personnel; rather, they imply certain extensions to the traditional crew rostering procedure. However, because these supplementary services do tighten the crew rostering problem, we also propose a means for levelling out these restrictions by raising the probability that a feasible solution exists: namely, downgrading and minimum crew flights. The application of the extended SWIFTROSTER algorithm to a numerical example is provided to substantiate the utility of language-oriented crew assignment and the downgrading concept.

Keywords: crew planning, personnel scheduling, rostering, workforce efficiency, service quality

1 Introduction

Tourism is a service-intensive industry that is characterized by a highly competitive market. The industry is exposed to two contradictory tendencies: on the one hand, the consumer expects a certain level of service quality, one which should preferably improve over time; on the other hand, qualified human labor is (usually) expensive and its costs increase over time. The adequate development and utilization of personnel provides the key tackling these two conflicting tendencies and outperforming competitors. Although organizational improvements and advanced planning tools have been already developed and are being implemented for most
of the relevant management activities optimization strategies, an important and wide application field with a high benefit potential remains largely disregarded: crew rostering. Crew rostering is a planning phase during which personalized work schedules are generated for the individual employees. Operators in the tourism industry who typically apply crew rostering include airlines, cruise lines, international hotel chains, and railway companies. However, many of these operators still perform this planning phase manually or by splitting the problem into smaller subproblems. While only limited work has been published so far on the topic of modeling the crew rostering problem (CRP), the need for efficient methods for generating computerized crew rosters is growing. This growing need reflects both the additional requirements and attributes needed in order to use personnel resources efficiently closer to their regulative limits, as well as the complexity implied by the simultaneous necessity of fully exploiting their skills - a complexity which is far too advanced to be managed manually. In principle, our suggestions for and ideas on service improvements are independent of the underlying planning tool; however, we will use a very efficient rostering algorithm - namely, SWIFTEROSTER - to discuss the following enhancements. We will pick airline crew rostering as an example as it is one of the most complex rostering applications, because (1) a crew member’s duty may cover a period of several days, (2) a work schedule is generated for a specific person with specific needs, and (3) a varying number of crew members with specific skills are required depending on the aircraft type. Moreover, the size of a real airline rostering problem and the typically large sets of data contribute to the complexity of the rostering procedure. In addition to the aforementioned complexity, the central role of airlines in the tourism sector also justifies the choice of this specific example. Travelling - a tourism consumer's core activity - often starts or ends by means of a plane trip. As a result, plane travel is an important factor in determining the consumer’s overall satisfaction and his views on the quality of tourism products and services. Airlines can directly improve the quality of their services and indirectly contribute to a trip’s overall quality by providing their passengers with a variety of supplementary services. This article will not only propose several specific supplementary services that can raise the level of consumers’ satisfaction while not directly impacting costs, but also present several strategies by which airlines can mobilize existing capabilities and make the skills of their workforces more readily available.

We will emphasize two beneficial service offerings: (1) language and (2) gender and special skills. At least one of the flight attendants on each flight should speak the language of the flight’s destination, so as to better service monolingual passengers. We will describe in detail three alternative implementation strategies: codeshare flights with mixed crews, small outward crew bases, and language-oriented crew assignment at the home base. Another cost-neutral supplementary service can be offered by providing mixed-sex cabin crews on flights to and from those Islamic countries in which crews consisting solely of female flight attendants are considered unacceptable due to cultural and religious considerations. All of these supplementary services do not require additional personnel - and in some cases, they do not even demand any specific training for the available work force); rather, they imply certain extensions to the traditional crew rostering procedure. However, because these supplementary services do tighten the CRP, we also propose a means for levelling out these restrictions by raising the probability that a feasible solution exists: namely, downgrading and minimum crew flights. The downgrading of some crew members based on the skills’ hierarchy for cabin crew.
Temporarily downgrading crew members from a higher to a lower rank even has a beneficial side-effect in that the service quality of a cabin crew containing one or more downgraded flight attendants is usually higher than that of a cabin crew with a conventional assignment of crew members. Whereas the implementation of minimum crew flights reduces the usual crew requirements on selected flight legs and supports a temporary freer allocation of resources. This paper discusses and formally presents those modifications that are necessary for implementing supplementary services and efficiency measures.

The remainder of the paper is structured as follows: Section 2 describes the basic crew rostering approach, and Section 3 explains the program flow of the SWIFTROSTER algorithm. Section 4 introduces new service concepts for improving the quality level of services and suggests how these can be integrated into the crew planning process. Three different strategies for integrating the language skills of the workforce are introduced in detail. Section 5 contains two alternatives for using the currently-available workforce efficiently: (1) downgrading, which is based on a hierarchy that structures the personnel resources and (2) minimum crew flights, which increases both flexibility and the likelihood of fulfilling other service requirements. Numerical results for the principal suggested means of improving the quality of service - namely, language and downgrading - are presented in Section 6, while Section 7 provides concluding remarks.

2 The Basic Rostering Model

Rostering is a specific type of scheduling and involves “the placing, subject to constraints, of resources into slots in a pattern” (Wren, p. 53). The term “rostering” derives from the practice of manually filling out a grid-lined sheet of paper in order to provide a graphical sketch of individual duty schedules. Rostering problems arise in numerous situations and cover a wide range of applications (e.g., airlines, railway companies, cruise lines, bus companies, call centers, hospitals, schools, etc.). Once shifts or duties that show the daily work of the personnel have been generated, these tasks are then placed into a roster that depicts which specific duties are to be performed by a particular individual on a particular day. Usually, the work pattern for an individual during any time period must conform to particular rules.

Airline crew rostering is a type of crew assignment procedure for airline crews that is specific to Europe and that takes into account pre-assignments (e.g., observer flights and training) and crew requests (e.g., for specific flights and days off) when constructing individualized schedules for each crew member. Airline crew rostering’s primary goal is to provide a fair-and-even distribution of the workload among all crew members and to maximize the crew members’ aggregated satisfaction with their individual schedules. The other widespread airline approach is the so-called “bidline” method, in which schedules are generated anonymously and employees choose their preferred schedules sequentially according to their seniority. “Preferential bidding” represents a compromise between the bidline and rostering approaches in that it generates personalized schedules that also take into account a set of bids that have been weighted to reflect the employees’ preferences.
Figure 1 depicts a segment of the graphic representation of a sample airline crew roster (König & Strauss, 1999). Each crew member has a so-called “line of work” that contains several duties (called "pairings"), which are represented by a bar whose length reflects the starting and ending times, as well as by an arrow that represents minimum rest times. For example, Catherine’s duties start on Monday evening with pairing 311 (together with Barbara and Dominique) and continue on with pairing 703 (together with Suzie and Natja).

<table>
<thead>
<tr>
<th></th>
<th>MO</th>
<th>TU</th>
<th>WE</th>
<th>TH</th>
<th>FR</th>
<th>SA</th>
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<td>P175</td>
<td>P183</td>
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<td>Catherine</td>
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<tr>
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<tr>
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<tr>
<td>Karin</td>
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<tr>
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<td>Natja</td>
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</tbody>
</table>

Fig. 1. A Sample Airline Crew Roster

To generate a roster automatically, we must map the problem into an adequate formalized model. The input data to our model is a set $W$ containing a large number of a-priori generated valid lines of work, a set of given crew members $M$, and a set of given pairings $P$, whereby each pairing $j$ requires a certain number $d_j$ of crew members.

We define a line of work $L$ as a subset of non-overlapping pairings $j \in P$, subject to constraints given by regulative requirements. Modeling the non-overlapping property, we denote $P_t$ as the set of pairings that cover a certain time $t$, therefore $|P_t| \leq 1$ has to hold for all $t$ within each line of work $L$. Furthermore, we define $W_k \subseteq W$ as the set of all lines of work that are possible for crew member $k$. All $W_k$ are disjoint, formally $W_{k1} \cup W_{k2} = \emptyset$ for all $k1 \neq k2$. Moreover, we define $W_j = \{L| j \in L\}$ as the set of all lines of work $L$ containing pairing $j$.

We introduce a binary variable $x_i \in \{0,1\}$ for each line of work in $W$. If the $i$-th line of work appears in the solution, then $x_i = 1$ otherwise 0. A utility value $u_i$ can be associated with each line of work, aiming at maximizing the total utility value of the solution.

$$\max \sum_{i=1}^{n} u_i x_i$$  \hspace{1cm} (1)

where $n$ is the number of lines of work in set $W$.

For each crew member $k$ we have generated a set $W_k$ of lines of work. Out of that set $W_k$ there must be exactly one schedule assigned to each crew member $k$. 

4
\[ \sum_{x_{ik}} x_i = 1 \quad k = 1, \ldots, m \]  
(2)

where \( m \) is the number of employees in set \( M \).

The demand \( d_j \) of crew members for pairing \( j \) has to be fulfilled for every pairing.

\[ \sum_{x_{ij}} x_i = d_j \quad j = 1, \ldots, q \]  
(3)

where \( q \) is the number of pairings in set \( P \).

Figure 2 provides as an example a selection from the set-partitioning tableau that results from the above-described model. (Note, that for reasons of readability all empty cells have a value of zero.) The selection includes two different crew members, Ariane and Nicole. The three lines of work (LoW) generated for Ariane are represented by column \( x_{(1,1)} \) to \( x_{(1,3)} \), while the two lines of work generated for Nicole are represented by column \( x_{(2,1)} \) to \( x_{(2,2)} \). For instance, Ariane’s first line of work includes the pairings \( p1 \) and \( p4 \) indicated by “1” in the respective row.

The crew restriction in the first row ensures that exactly one line of work is chosen for Ariane in a feasible solution (compare equation (2)). The pairing restriction in the last row ensures that pairing \( p4 \) appears exactly three times in a feasible solution - compare equation (3) - and guarantees that there are enough crew members on a flight.

<table>
<thead>
<tr>
<th>Ariane</th>
<th>Nicole</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoW</td>
<td>LoW</td>
</tr>
<tr>
<td>x(1,1)</td>
<td>x(1,2)</td>
</tr>
<tr>
<td>u(1,1)</td>
<td>u(1,2)</td>
</tr>
</tbody>
</table>

**Objective function**

\[ \Rightarrow \text{max} \]

**Crew restrictions**

<table>
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<th>1</th>
<th>...</th>
<th>= 1</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>...</td>
<td>= 1</td>
<td></td>
</tr>
</tbody>
</table>

**Pairing restrictions**

<table>
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<tr>
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<th>1</th>
<th>...</th>
<th>= 2</th>
</tr>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>...</td>
</tr>
</tbody>
</table>

Fig. 2. Sample Set-partitioning Tableau for the Crew Assignment Model

Comparatively little work has been published to date on the issue of modeling the CRP for airline applications (Barnhart et al. 1997, 2000). An enhanced crew rostering model that exploits problem-specific knowledge provides the basis for SWIFTROSTER, which is a branch-and-bound-like procedure that implements an algorithm in order to efficiently generate airline crew rosters (Dawid et al., 2000). As this model is typically applied to large sets of data, we place our emphasis on finding a feasible solution rather than maximizing any
particular utility function (cf. Wren, 1996; p. 53). Ryan (1992), who implements a comparable model, resolves this issue by applying linear programming techniques; however, other approaches might prove more efficient if no objective function is maximized.

Gamache et al (1998, p. 148) implement a similar model; however, they focus on the use of column generation to bring about optimization and restrict their study of the impact of pre-assignments to problem instances of rather limited scale (namely, ones in which only 22 employees are involved). Even recent academic publications (Gamache, 1998, 1999) have focused primarily on the search for feasible solutions; moreover, the optimization of lines of work as outlined in this body of work is applicable only for an individual crew member – and not for a flight crew as a whole. When the local optimization strategy presented in these publications is applied, a feasible solution must be found a least $m$ times, with $m$ corresponding to the numerical size of the crew. Consequently, a fast method for bringing about feasible solutions (even for medium-sized problems) is of great importance when this strategy is followed. Several academic papers (cf. Bianco et al., 1992, Caprara et al., 1998; Wren, 1996) have presented related rostering approaches for such challenges as the scheduling of mass transit personnel. However, the models presented in these papers cannot be applied to restrictive and complex CRPs in which lines of work must be generated in such a way as to meet the preferences and qualifications of each and every individual crew member.

3 The SWIFTROSTER algorithm

In the following section, the SWIFTROSTER algorithm is outlined and summarized in order to provide insight as to how solutions can be generated (for detailed description, see Dawid et al. (2000)). SWIFTROSTER is a recursive implicit enumeration approach based on the Davis-Putnam algorithm (Davis, 1960) which incorporates elements of constraint programming (i.e., propagation). The approach was inspired by Peter Barth's pseudo-boolean Davis-Putnam algorithm OPBDP (Barth 1996, pp. 75) and has been adapted to solve CRPs. Within this context, SWIFTROSTER only represents an instance of an implemented tool. Experiments with OSLMIP, a specific commercial branch-and-bound-based simplex solver for mixed-integer problems, showed that SWIFTROSTER is up to 1,000 times faster (the influence of loading times and the pre-solver was kept to a minimum in favor for OSLMIP). Similar results were obtained using ILOG: large CRPs could not be solved at all, and the solution of medium ones implied run times that are up to 500 times longer than SWIFTROSTER.

The SWIFTROSTER approach does not incorporate branch-and-bound in its traditional sense: there are no bounds to control the search in the solution space; also, we apply propagation to reduce the number of nodes being evaluated. However, SWIFTROSTER uses a branching strategy that – together with the variable selection – provides the crucial criteria making the algorithm so efficient. In the root of the enumeration tree, all variables $x$ are free variables and none has been set yet. The state of the model changes whenever a free variable is set to zero or one, which means that its selection or rejection is assumed for a certain line of work. A
feasible solution is reached when each free variable has been set to either zero or one and all restrictions have been fulfilled. In detail, this means that a branching variable is chosen out of the set of free variables in each enumeration node. A solution has been found and the algorithm comes to an end in the event that no free variables remain and the model continues to be in a feasible state at the same time. The model’s current state is stored before any changes are introduced to that state (i.e., before any variable is set); thereafter, the chosen variable is set to one constraint propagation is executed. Should the model remain feasible, a recursive examination of the next enumeration node at a deeper level is performed. The model’s old state must be restored and the chosen variable set to zero in the event that it becomes infeasible after the state change or if backtracking occurs on a deeper level of the enumeration tree. In the event that this step again produces an infeasible solution, the current enumeration node is dropped and backtracking is performed. Should this not be the case, then the procedure is repeated with another free variable. Constraint propagation might lead to other free variables being set to zero or one simultaneously. This constraint propagation process limits the depth of the enumeration tree to the number of crew members $m$. The flow chart in Fig. 3 shows this recursive process for an enumeration node.

![Figure 3. SWIFTROSTER Program Flow](image-url)
The heuristic variable selection and branching strategy have a substantial impact on the performance of the SWIFTROSTER algorithm. In each enumeration node, we select a branching variable that helps to satisfy those constraints that impose the tightest bound to the solution. In fact, we compute the tightness of each pairing constraint. One of our model’s significant properties lies in the fact that the feasible solutions that it produces all have a characteristic ratio of variable \( x_i \) set to one versus those variables that have been set to zero: \( m:(n-m) \), where \( m \) is the number of crew members and \( n \) is number of lines of work. Because \( n \gg m \) in such variables, significantly more variables are set to zero than to one. In light of this fact, a branching strategy is efficient for those problems in which the “one-branch” is explored in every enumeration node first of all, whereas the “zero

In order to assure an efficient navigation through the enumeration tree, it is essential to find out as soon as possible if the problem might become infeasible. The computational effort for testing for infeasibility after every choice of a LoW is relatively low (only one comparison per constraint) compared to the search effort in a subtree that cannot succeed.

4 Integrating Service Concepts into the Crew Planning Process

Besides pricing strategy, airlines rely on their level of service as an essential factor in differentiating themselves from their competitors. Airlines try to stand out among their competitors by providing superior cabin service and by offering a product with a unique selling point (USP) – this is especially true for the business class segment, which is largely free of price competition. This marketing strategy also has a striking effect on the process of crew assignment, particularly for cabin crews.

The following chapters show how marketing decisions influence the construction of crew duty rosters, as well as how these requirements can be introduced into the mathematical crew assignment model that had been presented above.

4.1 Language

One of the results of the boom in the tourism industry is that more people are travelling to a larger number of foreign destinations without speaking any language other than their own. At least one crew member should have a good command of a passenger’s mother tongue in order to assure that monolingual passengers are also provided with optimal comfort (and security) on their journey. The polyglot nature of our global society will clearly make it impossible to always fully realize this aim. Therefore, this supplementary service should be confined to flights where communication problems arise regularly; such destinations include not only Japan (Japanese) and Africa (French), but also South and Central America (Spanish and Portuguese). As a consequence, at least one of the flight attendants on each flight should speak the language spoken at the flight’s destination.
There are several ways for solving the language problem in crew planning. Because crew assignment is increasingly being handled by automated planning systems, the requirements must be implemented into a mathematical crew assignment model. The following section introduces three ideal approaches: the “codeshare flights” approach is based on codeshare partners whose crews have the required language qualifications, whereas the approach of using “small outward crew bases” is strongly restricted by economic criteria. The third approach of “language-oriented crew assignment at the home base” is not impacted by these restrictions, but its success depends on the availability of a sufficient supply of qualified crew members.

4.1.1 Codeshare Flights with Mixed Crews

Codeshare flights are flights that are commonly carried out by only one airline, but are offered under different flight numbers by the participating codeshare airlines. The motivation for this approach often lies in the fact that airlines want to offer their customers a larger flight network. With the emergence of global airline alliances, the number of codeshare flights has increased significantly. In some cases, codeshare flights have crews that have been provided jointly by the participating airlines; for example, during Austrian Airlines’ cooperation with All Nippon Airways (ANA), Japanese native speakers were always aboard flights from and to Japanese destinations due to the fact that part of the crew was provided by ANA. Making such an offering part of the planning process and integrating it into the rostering procedure will help to anchor this service as part of an airline’s marketing policies.

Currently, codeshare flights are carried out exclusively by one airline, while the other participating airlines only buy seat contingents that they then sell on their behalf. However, it would be advantageous to use crews consisting of qualified personnel from the participating airlines on those codeshare flights on which language barriers could pose a challenge. Each crew planning department of the involved partner airlines must assign an agreed number of qualified crew members to such flights. The basic crew assignment model does not need to be extended for this approach; only the demand vector $d$ needs to be adjusted accordingly.

Although this method is very simple in its realization, it is only useful for a limited number of flights, i.e., for those codeshare flights for which the partner airline(s) can provide crew members with the required language skills. Codeshare co-operations between European airlines and Asian and North or South American partners provide examples of this approach.

4.1.2. Small Outward Crew Bases

Due to the fact that there is usually not sufficient staff with the required qualifications available in an airline’s home country, it is often advantageous to create small crew bases at outward stations. Such a crew base would only employ as many crew members as are needed for the respective flight rotation. This method is generally used for long-haul flights for which no codesharing agreement with an airline based at the destination exists.
An additional advantage can be achieved by utilizing the differences that may well exist between the wage levels found at the airline’s own home base and those found at the respective destination.

Of course, this method implies a greater challenge for the crew planning department, because the foreign crew base needs to be included into long-term and medium-term planning. Moreover, this method necessitates essential changes in the mathematical crew assignment model.

The foreign crew base supplies a certain number of crew members for all flights to and from this particular destination. The flight rotations (pairings) used in crew planning complement the original ones, of course. Consider an airline that flies from Vienna (VIE) to Narita (NRT) in Japan on weekdays 2, 4 and 6 (Tuesday, Thursday, and Saturday). Each flight needs at least ten cabin attendants. These flights can be covered from the home base by three rotations \( P_1, P_2, \) and \( P_3 \), each having a demand for ten crew members; alternatively they can be covered from the NRT crew base by the complementary rotations \( P^{*4}, P^{*5}, \) and \( P^{*6} \). Figure 4 shows these rotations graphically. If, for example, the complementary rotation \( P^{*4} \) is staffed with two Narita employees, the demand for rotation \( P_1 \) can be reduced to eight crew members.

![Day Schedule](image)

<table>
<thead>
<tr>
<th>Homebase Rotation</th>
<th>MO</th>
<th>TU</th>
<th>WE</th>
<th>TH</th>
<th>FR</th>
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<tr>
<td>( P_1 )</td>
<td>VIE-NRT</td>
<td>NRT-VIE</td>
<td></td>
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<tr>
<td>( P_2 )</td>
<td>VIE-NRT</td>
<td>NRT-VIE</td>
<td></td>
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<td>( P_3 )</td>
<td>VIE-NRT</td>
<td>NRT-VIE</td>
<td></td>
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<tr>
<td>next wk</td>
<td>NRT-VIE</td>
<td>VIE-NRT</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>NRT-Base Rotation</td>
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<tr>
<td>( P^{*4} )</td>
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<td>NRT-VIE</td>
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<tr>
<td>next wk</td>
<td>VIE-NRT</td>
<td>NRT-VIE</td>
<td></td>
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<tr>
<td>( P^{*5} )</td>
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<tr>
<td>( P^{*6} )</td>
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<td>VIE-NRT</td>
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Fig. 4. Example for Complementary Rotations at a Foreign Crew Base

Formally, such requirements can be included into the basic crew assignment model. Besides the set of crew members \( M \) at the home base, we have an additional set of crew members \( O \) at an outbound base. A set of complementary pairings \( Q \) exists for this outbound base, as does a set of lines of work \( V_k \subseteq V \) for these crew members \( k \). The crew restriction of our basic model now becomes:

\[
\sum_{i \in W_k} x_i = 1 \quad k = 1, \ldots, m
\]

\[
\sum_{i \in V_k} x_i = 1 \quad k = 1, \ldots, o
\]

Due to the fact that a pairing \( j \) is normally covered by two complementary pairings for the outbound and the inbound flight, we introduce the set \( V_{js} \) as the lines of work of outbound base crew members that contain the
complementary outbound pairing for pairing \( j \) and \( V_j \), as the lines of work of outbound base crew members that contain the complementary inbound pairing for pairing \( j \). The pairing restriction for our model can now be rewritten as:

\[
\sum_{i \in W_j} x_i + \sum_{v \in V_j} x_v \geq d_j, \quad j = 1, \ldots, q
\]

(6)

\[
\sum_{i \in W_j} x_i + \sum_{v \in V_j} x_v \geq d_j, \quad j = 1, \ldots, q
\]

(7)

Figure 5 depicts a segment of a sample extended set-partitioning tableau incorporating language restrictions; such a tableau results from the implementation of the model described above and is analogous to that depicted in Figure 2. Consider the VIE-NRT flight on Tuesday from Figure 3 and assume that there are already nine crew members assigned to it. The tenth position can either be filled from the home base by Mary (LoW1) or from the NRT base by Chen (LoW1) or Yuan (LoW2). For instance, if we chose Chen, then we necessarily have to assign Yuan to the return flight NRT-VIE on Friday.

4.1.3. Language-oriented Crew Assignment at the Home Base

The alternative approach of using language-oriented crew assignments at the actual home base remains viable in the event that both of the methods mentioned above cannot be applied, whether as a result of the absence of a respective codeshare agreement or due to the fact that the creation of a small outward crew base would be economically inefficient.

An approach based on the language qualifications of the home base crew members requires long-term and short-term decisions: first, the planners must consider language knowledge in their crew capacity planning, so
as to ensure that a sufficient number of crew members with the required language qualification are available. If necessary, this potential can be improved over the medium-term by offering language courses; however, an adequate hiring strategy that takes language requirements into account is even more important within this context.

The short-term problem in crew planning is of greater relevance for this paper. The challenge that this problem poses lies in optimally assigning the scarce resource of qualified crew members to important flights.

For this method, the basic crew assignment model introduced earlier is extended with additional constraints that ensure that the demand for crews with foreign language skills is fulfilled; the model is altered accordingly. It may well happen that not all flights can be staffed with language-skilled crews in the event that crew resources are tight. To nevertheless obtain a realizable crew schedule, such language restrictions are modeled not as hard rules, but rather as soft rules. The goal function is used to drive the model towards a solution that assigns the highest possible number of flights with the crew composition that they require.

Formally, we introduce a subset \( M_l \subseteq M \) as the crew members that possess the language qualification \( l \). Furthermore \( d_{l(j)} \) denotes the number of crew members of pairing \( j \) that are required to possess language qualification \( g \). Moreover, for those pairings that require a crew with special language qualifications, we introduce an additional pairing constraint:

\[
\sum_{x \in W_j, y \in M_l} x_i + y_l \geq d_{l(j)}, \quad j = 1,...,q
\]  

The integer variable \( y_l \) is an artificial variable used to calculate a negative penalty for unmatched language requirements in the goal function. The goal function therefore becomes:

\[
\max \sum_{i=1}^{n} u_i x_i - \sum_{v_l(j)} v_l y_l
\]  

where \( v_l \) is the penalty for having no employee with the required language on board.

4.2 Gender and Special Skills

To emphasize the individual service characteristics of an airline, crew members are sent to training sessions and seminars aimed at providing them with additional qualifications. For example, crew members can be trained to serve as sommeliers, advising passengers about the high-quality wines offered on board. If such a service was to be offered on all flights, then at least one crew member with such a qualification would need to be on each and every flight. At the same time, economic reasons and/or the lacking individual prerequisites
make it impossible to provide such training to all crew members. Therefore, the problem is shifted towards the crew planning department, which must ensure that such a marketing measure can actually be realized.

Another free supplementary service could be offered on flights from and to those Islamic countries in which cabin crew consisting solely of female flight attendants are considered unacceptable due to the passengers’ cultural background: these states include Saudi Arabia, Kuwait, Qatar, United Arab Emirates, Iran, Iraq, Pakistan, Algeria, and Morocco. There should be a certain ratio of male flight attendants on each flight, not least due to the fact that passengers from these countries are more likely to follow instructions given by a male flight attendant in the event of an emergency. Taking these cultural factors into account during the operational crew planning phase might ensure that at least one male crew member is on board of all flights to and from the Middle East.

Both optional requirements can be implemented into the crew assignment model through additional constraints (König & Strauss, 1999).

We introduce a subset \( M_g \subseteq M \) to represent the crew members that possess the special qualification \( g \). Furthermore, \( d_{g(j)} \) denotes the number of crew members of pairing \( j \) that are required to possess special qualification \( g \). Additionally, for those pairings that require a special regulation we introduce an additional pairing constraint:

\[
\sum_{i \in W_j} x_{ij} + y_{gj} \geq d_{g(j)} \quad j = 1, \ldots, q
\]  

(10)

The integer variable \( y_{gj} \) is an artificial variable used to calculate a negative penalty for unmatched qualification requirements in the goal function. The goal function therefore becomes:

\[
\max \sum_{i \in W} u_i x_{ii} - \sum_{i \in W, j \in P} v_{ij} y_{gj}
\]  

(11)

where \( v_{gj} \) is the penalty for having no employee with the required special regulation on board.

5 Enhancing Crew Assignment Efficiency

The supplementary services proposed above tend to tighten the CRP and makes it more difficult to find a feasible solution. In order to level out these additional restrictions, we also suggest measures that raise the probability that a feasible solution exists: namely, the temporary downgrading of some crew members based on the skills hierarchy for cabin crew. The downgrading of crew members from a higher to a lower rank even has
a beneficial side-effect: the service quality of a cabin crew that consists of one or more downgraded flight attendants is generally higher than that of a “regular” cabin crew without downgraded crew members. In contrast, the implementation of minimum crew flights reduces the usual crew requirements on selected flight legs and helps to set free resources. This paper discusses and formally presents those modifications that are necessary for implementing the supplementary services and the efficiency measures.

5.1 Downgrading

For the jobs on a flight to be performed by crew members according to their rank in the organizational hierarchy is common practice in the airline industry. Generally, the purser holds the highest rank among the cabin crew, while the senior flight attendant holds the second-highest rank and the junior flight attendant represents lowest rank. In his paper on crew rostering, Ryan states that the "full Rostering problem can usually be broken into smaller independent subproblems corresponding to groups of crew members of same rank” (Ryan, 1992, p. 460). In principle, this statement is correct, but Ryan’s suggested approach is not always applicable to real world problems and can actually reduce the likelihood of finding any feasible solution.

In the following we will introduce a new approach for handling tight problems by means of temporarily downgrading crew members from a higher rank to a lower rank in one step (Dawid et al., 2000). The temporary downgrading of crew members has a beneficial effect in that the service quality of a cabin crew containing one or more downgraded flight attendants is usually higher than that of a cabin crew with a conventional assignment of crew members. Additional benefits of the downgrading concept include the higher likelihood of finding feasible solutions for tight scheduling problems, as well as the stabilization of the employment level over time.

As an example, this article addresses the situation faced by an airline that has a profusion of senior flight attendants and a simultaneous shortfall in the number of junior employees. Traditional models (i.e., those that do not integrate downgrading) may fail to bring about a feasible solution due to the shortage in lower-ranked flight attendants. The downgrading option provides the only opportunity for bringing about a temporary levelling among roles that are adjacent to each other in the job hierarchy - and thus, for possibly producing a feasible solution. The goal of distributing a cabin crew’s workload in a fair-and-even manner rests to a significant degree on the application of downgrading to bring about a levelling among an airline’s personnel. Section 4 provides a numerical example for a situation like that described above.

Two new sets are introduced to account for downgrading in certain pairings: let $W_{jH} \subseteq W_j$ denote the set of lines of work for pairing $j$ for higher-ranked employees and $W_{jL} \subseteq W_j$ the set of lower-ranked employees; the sets are both disjoint $W_{jH} \cap W_{jL} = \{ \}$. As a result, $d_{jH}$ is the demand created by pairing $j$ for employees of higher rank and $d_{jL}$ is that for those of lower rank.
Without restriction to generality, restriction (3) is now substituted by two new restrictions (12) and (13), which are:

\[
\sum_{i \in w_{ji}} x_i \geq d_{ji} \quad j = 1, \ldots, q
\]  

(12)

\[
\sum_{i \in w_{ji}} x_i + \sum_{i \in w_{ji}} x_i = d_{ji} + d_{ji} \quad j = 1, \ldots, q
\]  

(13)

Constraint (12) allows overcoverage of higher-ranked employees, whereas (13) ensures that the total demand is covered exactly. In the event that downgrading is regarded as undesirable and is consequently desired to remain low, a penalty can be applied to downgrading by assigning a negative objective value to the slack variable of restriction (12). Generalizing the above for \( r \) ranks, one can observe that the set of constraints generally becomes somewhat more complicated if downgrading is allowed.

5.2 Minimum Crew Flights

Due to cost and efficiency, but also because of scarce crew resources, it is not possible to always assign a standard number of crew members to each flight. However, this is not always necessary: for instance, if a flight’s passenger utilization is only around 50 per cent, the number of cabin attendants on such a flight can be reduced without decreasing the service standard. Of course, such minimum crew flights will happen very rarely - and even then only on those flights where the passenger yield can be anticipated to be low.

To cope with this fact, we introduce into our model the integer variable \( y_j \) for minimum crew flights. This variable holds the number of crew members that have been reduced on such a flight. The maximum value for \( y_j \) is limited by \( m_j \).

The pairing demand restriction implies this minimum crew potential as follows:

\[
\sum_{i \in W_j} x_i + y_j \geq d_j \quad j = 1, \ldots, q
\]  

(14)

\[
y_j \leq m_j
\]  

(15)

The objective function is extended by a penalty for each minimum crew flight

\[
\max \sum_{i=1}^{n} u_{ij} x_{ij} - \sum_{j=1}^{q} v y_j
\]  

(16)

where \( v \) is the penalty value for a flight that is assigned with minimum crew.
6 Results

By using real data from a medium-sized European airline to provide sample results, this article demonstrates the “real-world” extension and adaptation of the enhanced model to generate schedules that increase the quality level of the services provided to passengers. The test instances were computed using an adaptation of SWIFTROSTER, an efficient C++ implementation for the CRP (for details see Dawid et al. (2000)), on a Pentium II running at 300MHz with 196 MB of memory.

The application of the extended algorithm to a numerical example is provided to substantiate the utility of the language-oriented crew assignment and the downgrading concept.

6.1 Language-oriented Crew Assignment Example

Table 1 provides an example that demonstrates how language constraints improve the solution for a long-haul rostering problem. Out of the 45 crew members \( m \), four have a good command of French \( m_F \) and further six crew members speak Spanish \( m_S \). These crew members must be assigned to 60 long-haul pairings \( q \), each demanding between two and three crew members. To enhance the cabin service for non-German or non-English speaking passengers, five pairings \( q_F \) should be staffed with at least one French-speaking crew member and thirteen pairings \( q_S \) with at least one Spanish-speaking crew member.

First, the problem is solved without any language constraints. The assignment of qualified crew members to pairings that require French or Spanish is done randomly. In the solution found by this approach, only three out of five pairings fulfil the French language requirement \( R_F \), whereas ten out of thirteen pairings fulfil the Spanish language requirement \( R_S \). This approach leads to a fulfillment level \( ff_F \) and \( ff_S \) of 60 per cent and 77 per cent, respectively. Adding language constraints to the model results in the total fulfillment of language requirements. The service quality with regard to language offerings increases by 40 per cent on flights requiring French and 23 per cent on flights requiring Spanish – this increase in service quality can be achieved without incurring any additional costs for the airline.

<table>
<thead>
<tr>
<th></th>
<th>( m, m_F, m_S )</th>
<th>( q, q_F, q_S )</th>
<th>( R_F )</th>
<th>( ff_F )</th>
<th>( R_S )</th>
<th>( ff_S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random language assignment</td>
<td>45, 4, 6</td>
<td>60, 5, 13</td>
<td>3</td>
<td>0.60</td>
<td>10</td>
<td>0.77</td>
</tr>
<tr>
<td>Language-oriented assignment</td>
<td>45, 4, 6</td>
<td>60, 5, 13</td>
<td>5</td>
<td>1.00</td>
<td>13</td>
<td>1.00</td>
</tr>
<tr>
<td>Improvement</td>
<td></td>
<td></td>
<td>2</td>
<td>0.40</td>
<td>3</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Tab. 1. Improvements Due to Additional Language Offerings

6.2 Downgrading Example

Table 2 provides an example with 55 crew members \( m \), of which 25 are high-ranked and 30 members are lower-ranked. These crew members must perform 280 pairings \( q \), each requiring one higher- and one lower-
ranked crew member. Without downgrading, no solution can be found for the lower rank subproblem, whereas the higher rank problem can be solved easily. Introducing the downgrading concept and concatenating these two problems into one extends the problem to 55,000 columns \( n \) (lines of work) and 560 rows for the pairing constraints and another 55 rows for crew constraints. We can now find a solution within a few seconds: the solution generated contains 65 pairings in which someone is downgraded to a lower position.

<table>
<thead>
<tr>
<th></th>
<th>( m )</th>
<th>( q )</th>
<th>( n )</th>
<th>CPU-time</th>
<th>solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher ranked</td>
<td>25</td>
<td>280</td>
<td>25,000</td>
<td>0.84</td>
<td>found</td>
</tr>
<tr>
<td>Lower ranked</td>
<td>30</td>
<td>280</td>
<td>30,000</td>
<td>n/a</td>
<td>not found</td>
</tr>
<tr>
<td>High &amp; low</td>
<td>55</td>
<td>280</td>
<td>55,000</td>
<td>3.60</td>
<td>found</td>
</tr>
</tbody>
</table>

Tab. 2. An Example of Downgrading

7 Conclusion

The competitiveness of a company in the tourism industry is determined to a large degree by the service quality offered by that company. At the same time, the hiring and retention of qualified staff involves significant expenses for firms in the tourism industry. For this reason, tourism-related companies can only stand out against their competitors by being showing greater efficiency in using their workforce, i.e., by more fully exploiting their employees’ skills. Although the general development in the tourism sector suggests a reduction of inclusive services, this article demonstrates the existence of “hidden” potentials for service quality improvements. This paper suggests as examples two measures by which the firms in the airline industry can raise their service level without generating any additional costs. However, these service quality improvements can only be achieved by using sophisticated and powerful rostering tools. As human resources are usually scarce, we also presented two concepts that contribute to solving tight rostering problems without diluting service quality. The numerical results provided by sample applications of these procedures substantiate the suggestions put forward in this paper. Although the presented study uses examples from the airline industry, our concepts could easily be adapted for other applications, e.g., cruise lines, international hotel chains, or railway companies.

References


