GROUP X7: A New Departure Hall

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May 11, 2017

Abstract

In this report we look at Security Personnel planning for a major Dutch airport. We try to plan the Security Marshalls to safely cover the Security Check of the new departure hall, such that the costs are minimized. First we consider a basic problem, in which specialized Marshall shifts are disregarded. The problem can be formulated as an integer linear programming problem using two different formulations; the Implicit Formulation and the Set Covering Formulation. The problem can be extended by splitting the breaks and adding Sniffer Dogs. Next we extend our basic problem by including Bomb-le bees and parttimers. Furthermore we will perform sensitivity analysis by varying some constraints. The results show that the optimal personnel costs are the same for both formulations, however the solutions are not unique. There exist different schedules to get to the same costs. The Implicit Formulation is on average faster than the Set Covering Problem formulation.

1 Introduction and Problem Description

The airport we are analyzing is among Europe's busiest airports based on total passenger traffic in 2015. Recently, during summer season, there has been a remarkably increase in number of passengers flying to Netherlands via this airport. This sudden surge has put severe pressure on the operating capacity of the airport and exposed several constraints in the airport's structural system. Despite the fact that a new departure hall has been opened on April 13, 2017, the airport still struggles to cope with the rapidly increasing number of passengers. One of biggest issues is recorded at the security department: long queues of passengers are persistent due to the lack of security personnel.

In this report, we focus on the demand of Security Marshalls in the new departure hall. Due to recent budget-cuts, the number of Security Marshalls is limited. There are strict labor rules set by the Military and European legislative for the shifts of the Security Marshalls. Therefore the Security Marshalls need to be planned efficiently such that the demand is met and the costs are minimized. The demand depends on the time of the day, the number of departing flights and expected number of travelers in the departure hall. The departure hall opens between 06:00 and 00:00 and the flight schedule is the same every week. Hence, we consider the demand per day for a week.

Research into labour-schedule optimization using linear-programming goes back to Dantzig (1954), where he uses a set covering formulation in which all possible shifts that can be performed by the personnel are listed explicitly. More recently, in a paper by Thompson (1995), linear programming is used to solve the same problem by an implicit formulation instead, and thus not requiring to list a potentially enormous amount of shift-possibilities. In this paper, both approaches shall be looked into.

First, we formulate the basic problem as an integer linear programming problem using the Implicit Formulation based on the paper by Thompson (1995). Next, we formulate the basic problem as a Set Covering Problem using the paper by Dantzig (1954). We also extend our problem by adding Sniffer Dogs and Specialized Security Marshalls, changing the breaks, adding Bomb-le bees, creating parttimers and by performing sensitivity analysis.
We find that the Implicit Formulation has the fastest computation time, especially for a more extended problem.

2 Mathematical Formulations and Solution Approach

2.1 Data

The dataset consists of the required number of Security Marshalls per half hour. The departure hall opens from 06:00-00:00 and the flight schedule at this airport repeats itself every week. Therefore the dataset for the basic problem consists of the required number of normal Security Marshalls (type = 1) per day of the week for 36 periods.
When Sniffer Dogs (type = 3) and specialized Security Marshalls (type = 2) are included, an extra data set is presented the minimal number of dogs needed per half hour. This dataset consists of the number of dogs needed per day of the week for 36 periods. These dogs should be accompanied by specialized Security Marshalls. Therefore this dataset also shows of the number of specialized security Marshalls needed per half hour.

2.2 Basic problem: Implicit formulation

Firstly, we define the basic problem as an integer linear programming problem using the implicit formulation based on Thompson (1995). For the basic problem, an assumption is made that only normal Security Marshalls exist and the specialized Marshall shifts are disregarded. Hence, there is only a single shift type for this basic problem. Since these shifts have the same cost, per working period, minimizing the cost of the schedule is equivalent to minimizing the number of periods worked. Below the necessary variables, parameters, sets and constraints are defined so as to formulate the problem using the implicit formulation.

Notation

Decision variables:
s_{tp}: number of shifts starting in period p
f_{tp}: number of shifts ending in period p
m_{tp}: number of breaks in shifts starting in period p

Parameters:
For the parameters we refer to table 6 in the Appendix. In the basic problem there is only one shift type, namely Normal Security Marshalls ($t = 1$).

Sets:
p $\in$ [1, ..., 36]

Subsets:
T_m: shift types that require a meal break (types 1 and 2 only)
$XAMB$: shift types requiring maximum post-meal-break work stretch restrictions ($t \in T \mid xamb_t < xl_t - nbmb_t - mbl_t$)
$XBMB$: shift types requiring maximum pre-meal-break work stretch restriction ($t \in T \mid xbmb_t < xl_t - namb_t - mbl_t$)

Formulation basic problem

$$\min Z = \sum_{t \in T} c_t \cdot [\sum_{p=ef_t}^{P} p \cdot f_{tp} - \sum_{p=1}^{ls_t} (p-1) \cdot s_{tp}] - (c_t \cdot mbl) \cdot [\sum_{p=emb_t}^{lmb_t} m_{tp}] \tag{1}$$

In our objective (1) we want to minimize the total costs. The working periods are calculated by summing the difference between shift finishing and starting times and subtracting the number of employees on work break. To get the total costs we multiply the working periods by the costs per period.

Subject to:

$$\sum_{t \in T} [\sum_{j=1}^{p} s_{tj} - \sum_{j=ef_t}^{p-1} f_{tj}] - \sum_{t \in T} \sum_{j=p-mbl_t+1}^{p} m_{tj} \geq d_{tp} \; for \; p = 1, ..., P \tag{2}$$

The first restriction (2) makes sure that for each planning period there is enough staffs to provide the desired level of service. We sum the people who started minus the people who finished, to get the number of employees currently working and then subtract the number of employees on their break. This number should be bigger or equal to number of Security Marshalls needed in this period.

$$\sum_{p=1}^{ls_t} s_{tp} - \sum_{p=ef_t}^{P} f_{tp} = 0 \; for \; t \in T, \tag{3}$$

The second restriction (3) equates the number of shifts starting to the number of shifts finishing. Every employee who starts a shift should finish work in the given time span.

$$\sum_{p=1}^{i} s_{tp} - \sum_{p=ef_t}^{i+nl_t-1} f_{tp} \geq 0 \; for \; t \in T \; and \; i = 1, ..., ls_t - 1, \tag{4}$$

This constraint (4) imposes the minimum overall shift lengths. This is done by first specifying that fewer shifts cannot start in period one then finish in period 12. There are no finish variables defined for period one through 11. Also, fewer shifts cannot start in periods one and two then finish in periods 12 and 13, etc.

$$\sum_{p=1}^{i} s_{tp} - \sum_{p=ef_t}^{i+xl_t-1} f_{tp} \leq 0 \; for \; t \in T \; and \; i = 1, ..., P - xl_t, \tag{5}$$

The next restriction (5) imposes the maximum overall shift lengths. Since shifts cannot exceed 17 periods, more shifts cannot start in period one than finish in period 12 through 17, etc.

$$\sum_{p=1}^{ls_t} s_{tp} - \sum_{p=emb_t}^{lmb_t} m_{tp} = 0 \ for \ t \in T_m \tag{6}$$

The number of shifts equals the number of breaks scheduled. For every working Security Marshalls a break should be scheduled (6).

$$\sum_{p=1}^{i} s_{tp} - \sum_{p=emb_t}^{i+nbmb_t} m_{tp} \geq 0 \ for \ t \in T_m \ and \ i = 1, ..., ls_t - 1, \tag{7}$$

This restriction (7) imposes the minimum work periods before a break. First, the number of shifts starting in period one must equal or exceed the meal break commencing in period two. Next the number of shifts starting in periods one and two must equal or exceed the number of meal breaks commencing in periods two and three, etc.

$$\sum_{p=i}^{P} s_{tp} - \sum_{p=emb_t}^{i+xbmb_t} m_{tp} \leq 0 \ for \ t \in XBMB \ and \ i = 1, ..., ls_t - 1, \tag{8}$$

This restriction (8) imposes the maximum work periods before a break. First the number of shifts starting in period one should be smaller or equal to the number of employees who start their break in period 2 until 11. The number of shifts starting in period two should be smaller or equal to the number of employees who start their break in period 3 until 12, etc.

$$\sum_{p=1}^{i} f_{tp} - \sum_{p=i-namb_t-mbl_t+1}^{lmb_t} m_{tp} \geq 0 for \ t \in T_m \ and \ i = ef_t + 1, ..., P, \tag{9}$$

This restriction (9) imposes the minimum work periods after a meal break. First the number of shifts finishing in period 36 must equal or exceed the number of meal breaks commencing in period 34. Next, the number of shifts finishing in periods 35 and 36 must equal or exceed the number of meal breaks commencing in periods 33 and 34.

$$\sum_{p=i}^{P} f_{tp} - \sum_{p=i-xamb_t-mbl_t+1}^{lmb_t} m_{tp} \leq 0 \ for \ t \in XAMB \ and \ i = ef_t + 1, ..., P, \tag{10}$$

The maximum work periods after a break are imposed in restriction (10).

$$f_{tp}, m_{tp} \geq 0 \ and \ integer \ for \ t \in T \ and \ p = 1, ..., P \tag{11}$$

Restriction (11) imposes that the decision variables are non-negative integers.

$$s_{tp} \geq 0 \ and \ integer \ for \ t \in \{1, 2\} \ and \ p = 1, ..., 25 \tag{12}$$

Restriction (12) imposes that no shifts are started after period 25.

2.3 Basic problem: Set Covering Problem

Secondly, we define the basic problem as an integer linear programming problem using the Set Covering Problem formulation. The formulation is based on Dantzig (1954). For this formulation a zero/one matrix can be created in Matlab containing all the possible shifts, where each column represents a shift, with 36 rows representing each period and where a 1 represents a working period and a 0 a non-working period (possibly a break). It is therefore the matrix containing all the values a_{jt} defined below. These shifts are based on the labor rules set by the Military and the European Legislative. A shift may last between 12 and 17 periods and should have a cohesive break of two periods. This break can not be at the beginning or at the end of a shift and the working time before and after a break may not be longer than 10 periods.

Notation

Decision variables:

x_j: The number of times that shift j is performed.

Parameters:
c_j: The cost of shift j, number of work periods times the costs of one period. These costs are 20 per period for a normal Security Marshall.
a_{tj}: Considering shift j, this variable equals 1 if t is a work period in this shift and 0 otherwise.

Sets:
j ∈ [1, 2, ..., 1115]
t ∈ [1, 2, ..., 36]

<u>Formulation basic problem</u>

$$min \sum_{j=1}^{1115} c_j x_j \tag{13}$$

In our objective (13) we want to minimize the total costs. We sum over the number of times shift j is performed times the costs of shift j.

Subject to:

$$\sum_{j=1}^{1115} a_{tj} x_j \geq b_t \ for\ t = 1, ...36\ and\ j = 1, ..., 1115 \tag{14}$$

The satisfaction of the minimal number of Security Marshalls needed per period is given in our first constraint (14).

$$x_j \geq 0\ and\ integer\ for\ j = 1, ..., 1115 \tag{15}$$

Our second constraint implies that the number of times shift j is performed can not be negative (15).

2.4 Extensions

Splitting the break The problem is extended by splitting the cohesive break into two smaller breaks of half an hour each. Working time between such two small breaks may not be longer than 8 periods. We formulate this problem as an integer linear programming problem using the Set Covering formulation. We prefer this formulation over the implicit formulation, because the matrix containing all possible shifts is easily transformed for this case. After we find all possible shifts, the problem is an objective function with a set of 2 constraints, changed from the earlier problem only by addition of 7010 new possible shifts computed in Matlab.

<u>Notation</u>
Decision variables:
x_j: The number of times that shift j is performed.

Parameters:
c_j: The cost of shift j, number of work periods times the costs of one period. These costs are 20 per period for a normal Security Marshall.
a_{tj}: Considering shift j, this variable equals 1 if if t is a work period and 0 otherwise.

Sets:
j ∈ [1, 2, ..., 8125]
t ∈ [1, 2, ..., 36]

<u>Formulation modified problem</u>

$$min \sum_{j=1}^{8125} c_j x_j \tag{16}$$

subject to :

$$\sum_{j=1}^{8125} a_{tj} x_j \geq b_t \ for\ t = 1, ...36\ and\ j = 1, ..., 8125 \tag{17}$$

$$x_j \geq 0\ and\ integer\ for\ j = 1, ..., 8125 \tag{18}$$

Risk flights The new departure hall is also used for a number of 'Risk flights'. These flights are known to attract smugglers. For these flights, Sniffer Dogs (type = 3) are available who are trained to detect illegal drugs hidden in bags or in the clothing of the smugglers. These dogs may only be handled by specialized Security Marshalls (type = 2) and cannot work longer than 8 periods. The dogs need no break. One dog costs 5 euros per period and must be accompanied by one specialized security Marshall. The specialized Security Marshalls follow the same rules for shift and break duration as the normal Security Marshall and can also be used for regular tasks. A specialized Security Marshall costs 30 euros per period. We use the extra data set consisting of the number of dogs needed for each day of the week for 36 periods. We decided to use the implicit formulation for this problem, since it can be easily altered by adding a new type (dogs as type 4) and changing/adding a few constraints. The implicit formulation should be faster as well, rather than using large matrices in the Set Covering formulation.

Notation
Decision variables:
s_{tp}: number of shifts starting in period p for a type t shift
f_{tp}: number of shifts ending in period p for a type t shift
m_{tp}: number of breaks in shifts starting in period p for a type t shift

Parameters:
For the parameters we refer to table 6 in the Appendix. In this extended problem there are 3 shift types; normal Security Marshalls, specialized Security Marshalls and Sniffer dogs (type 1, 2 and 3, respectively).

Sets:
periods: p ∈ [1, ..., 36]
types: t ∈ [1, 2, 3]

Formulation Risk Flights Model:
The formulation for this extended problem is the same as the basic problem but we include 2 extra shift types. The demand constraint (2) is changed into two demand constraints for normal shifts and shifts for the dogs (19) (20). There are two extra constraints concerning the dogs added to our model (21) (22). Lastly, constraint (23) is added.

$$\sum_{i \in T_m} [\sum_{j=1}^{p} s_{ij} - \sum_{j=ef_i}^{p-1} f_{ij}] - \sum_{i \in T_m} \sum_{j=p-mbl_i-1}^{p} m_{ij} - [\sum_{j=1}^{p} s_{3j} - \sum_{j=ef_3}^{p-1} f_{3j}] \geq d_p \; for \; p = 1, ..., P \tag{19}$$

This constraint makes sure that the demand for the normal shifts is met by subtracting the number of dogs working in period p. Because the specialized Security Marshalls who are handling the dogs can not do the normal shift at the same time. (19)

$$\sum_{j=1}^{p} s_{3j} - \sum_{j=ef_3}^{p-1} f_{3j} \geq d_{dogs} \; for \; p = 1, ..., P \tag{20}$$

The demand for the dogs is given in constraint (20). It makes sure that for each planning period there are enough dogs to provide the desired level of service.

$$\sum_{j=1}^{p} s_{3j} \leq 5 \tag{21}$$

Restriction (21) imposes that there is a maximum of 5 dogs available.

$$\sum_{j=1}^{p} s_{3j} - \sum_{j=ef_3}^{p-1} f_{3j} - (\sum_{j=1}^{p} s_{2j} - \sum_{j=ef_2}^{p-1} f_{2j} - \sum_{j=p-mbl_2+1}^{p-1} m_{2j}) \leq 0 \; for \; p = 1, ..., P \tag{22}$$

This restriction (22) imposes that the number of specialized Security Marshalls in period p must be greater or equal to the number of Sniffer Dogs in period p.

$$s_{tp} \geq 0 \; and \; integer \; for \; t = 3 \; and \; p = 1, ..., P \tag{23}$$

Restriction (23) is added to ensure that dogs can start in periods 1 through 36.

2.5 Our extensions

Bomb-le Bees There has been a lot of research on sniffer bees. These bees are trained to detect bombs. The university of Cologne claims that the insects could eventually replace sniffer-dogs at airports. (Waterhouse, 2015). We are going to use these Bomb-le Bees (type = 4) to detect bombs in the new departure hall. An article from the daily mail describes that the trained bees work in units of 36 bees which are put into a hand-held detector used to detect the bombs (Macrae, 2013). The Bomb-le Bees work in units and on day 1 the airport receives 6 units of bees. Due to a mortality rate the number of units decreases by one every two days, leaving only half of the bees alive on the seventh day. We shall let the demand for bomb-detecting bees be equal to the demand for normal marshalls divided by 10 and rounded, reflecting the idea that if there are a lot of normal Security Marshalls needed the airport is probably quite busy and more bees will be needed to check for bombs. The Bomb-le Bees can also replace the Sniffer Dogs in detecting drugs if they are not busy detecting bombs, with one unit of bees replacing one dog. The bees do not have a restriction on working periods per day and they do not have breaks, but each living unit can only perform one shift per day. Furthermore, one specialized Security Marshall is needed per unit of Bomb-le Bees. According to the article by Macrae from the daily mail, these bees could cut costs by three-quarters when replacing dogs. Therefore we shall assume a unit of Bomb-le bees to cost 2.50 euros per hour.The formulation for this problem is the same as that for the risk-flight problem, except for a few changes:

$$\sum_{i\in T_m}[\sum_{j=1}^{p} s_{ij} - \sum_{j=ef_i}^{p-1} f_{ij}] - \sum_{i\in T_m}\sum_{j=p-mbl_i-1}^{p} m_{ij} - \sum_{t=3}^{4}[\sum_{j=1}^{p} s_{tj} - \sum_{j=ef_3}^{p-1} f_{tj}] \geq d_p \ for\ p = 1,...,P \tag{24}$$

Firstly, (19) is changed to (24) to include the fact that the special Security Marshalls must also handle the bees.

$$\sum_{t=3}^{4}[\sum_{j=1}^{p} s_{tj} - \sum_{j=ef_3}^{p-1} f_{tj}] - (\sum_{j=1}^{p} s_{2j} - \sum_{j=ef_2}^{p-1} f_{2j} - \sum_{j=p-mbl_2+1}^{p-1} m_{2j}) \leq 0 \ for\ p = 1,...,P \tag{25}$$

The same is done to change (22) to (25).

$$\sum_{t=3}^{4}[\sum_{j=1}^{p} s_{tj} - \sum_{j=ef_3}^{p-1} f_{tj}] \geq d_{dogs} + d_{bees} \ for\ p = 1,...,P \tag{26}$$

Furthermore (20) is changed to (26).

$$\sum_{j=1}^{p} s_{4j} - \sum_{j=ef_4}^{p-1} f_{4j} \geq d_{bees} \ for\ p = 1,...,P \tag{27}$$

Constraint (27) is added as the demand constraint for the bees.

$$\sum_{j=1}^{p} s_{4j} \leq number\ of\ living\ bee - units \tag{28}$$

Constraint (28) makes sure that only the living bees can be used, the amount of which depend on the day of the week.

$$s_{tp} \geq 0\ and\ integer\ for\ t = 4\ and\ p = 1,...,P \tag{29}$$

Lastly, (29) makes sure that bees can start in periods 1 through 36.

Parttimers Parttime working is very popular in the Netherlands. Therefore we include an extra type in our formulation, namely parttime normal Security Marshalls. These Security Marshalls work for 5 hours cohesive without a break. In this way, it follows the labor rules set by the Military and the European legislative because Security Marshalls are allowed to work for 5 hours without a break. We do this by including parttimers in the implicit formulation for the risk flights as type 5 and define the parameters for type 5. The parameters and their values are shown in table 8 in the appendix.

2.6 Sensitivity analysis

Breaks Breaks may not be at the beginning or at the end of a shift. However for a shift of 6 hours it is possible to have a break after 30 minutes or to only have 30 minutes of work left after a one hour break. This is not very realistic, hence, we change the minimum pre- and post-meal break working periods from 1 to 4. This means that Security Marshalls always work for a minimum of 2 hours before and after a break. We keep a maximum of 10 post- and pre-meal break working periods. The schedule will be less flexible and therefore we expect that the costs will go up. We use the extended model which includes the Sniffer Dogs.

Changing the demand We change the demand to see if the optimal personnel costs are sensitive for small changes. We decided to change the dataset for the normal shifts by adding and deleting one extra Security Marshall for every period.

3 Computational Experiments and Results

Evaluation of formulations In table 1 we present both formulations of the basic problem. We can compare the optimal personnel costs, the running times and the total number of employees for each day of the week. The optimal personnel costs (the objective value to be minimized) is the same for both formulations, however this solution is not unique as we can see in the table because the total number of Security Marshalls working per day is different for both formulations. Thus the two formulations give slightly different schedules, but with the same minimized cost. There isn't one unique best schedule for this problem. The solving time differs per day, however the Implicit Formulation is on average faster, and the difference is particularly visible on the seventh and fourth day.

Table 1: Comparison formulations basic problem

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
SCP: Optimal personnel costs	9180	9220	10660	11340	11500	8280	12720
IF: Optimal personnel costs	9180	9220	10660	11340	11500	8280	12720
SCP: Solving time	0.03	0.05	0.02	0.13	0.03	0.03	0.14
IF: Solving time	0.06	0.05	0.03	0.03	0.03	0.03	0.05
SCP: Total number of Security Marshalls	43	44	50	53	52	39	60
IF: Total number of Security Marshalls	44	44	48	53	53	37	56

SCP: The basic problem is defined as an integer linear programming problem using the Set Covering Problem formulation.
IF: The basic problem is defined as an integer linear programming problem using the Set Implicit Formulation.
This table shows the results for our basic problem using SCP formulation and Implicit Formulation. It shows the optimal personnel costs, solving time and total number of Security Marshalls per day.

Splitting the break The matrix with all the possible shifts in the Set Covering Formulation increases from 1115 shifts to 8125 shifts. We can see this increase in table 2 in the solving time of our problem. This also shows the weakness of the Set Covering Problem formulation. Given the larger amount of possible shifts, we expected a better solution to fit the constraints and give a smaller objective value. However, looking at the table, we see that the difference is small. The optimal costs per day are 20 euros less or equal to the solution of the basic problem. The optimal personnel costs remain unchanged for day 4, 6 and 7.

Table 2: Splitting the break using the SCP formulation

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	9160	9200	10640	11340	11480	8280	12720
Solving time	0.66	0.33	1.22	0.48	1.17	1.01	6.51
Total number of Security Marshalls	42	42	49	54	53	38	58

This table shows the results of including two seperate breaks of 30 minutes in our model using the Set Covering Problem formulation. It shows the optimal personnel costs, solving time and the total number of Security Marshalls per day.

Risk flights The personnel costs go up for this extended problem as we can see in Table 3. All 5 dogs are assigned to work each day. The number of specialized Security Marshalls changes from the number of dogs, because the dogs work less hours and the Marshalls need breaks. The solving time for day 1 is significantly higher than the other days. The reason may be that the demand for dogs on Monday is more complicated as every period a dog is scheduled.

Table 3: Implementing Sniffer Dogs using Implicit Formulation

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	10450	10640	11625	12610	12920	9110	14120
Solving time	3.95	0.08	0.14	0.08	0.13	0.11	0.11
Sniffer Dogs	5	5	5	5	5	5	5
Specialized Security Marshalls	4	5	3	6	5	4	5
Normal Security Marshalls	41	40	47	49	48	34	54

This table shows the results of Sniffer dogs were implemented by Implicit Formulation. The table shows the optimal personnel costs, solving time, total number of Sniffer Dogs, total number of specialized Security Marshalls and the total number of normal Security Marshalls for each day of the week.

Bomb-ble bees When adding the bee-units, we see in table 4 that on every day except for the first all still living bee-units are used. Because of their ability to take over the work of dogs for less money not all 5 dogs are used on every day now, with even zero being used on the first day. The overall costs rise due to the extra need to check for explosives using bees who require special Security Marshalls. The advantages of the bees (their ability to replace dogs and be able to work all day without breaks and be cheaper per period) are thus not sufficient to outweigh the extra costs from checking for explosives.

Table 4: Adding Bomb-ble Bees using Implicit Formulation

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	11638.75	11702.5	13081.25	14165	14675	10238.75	15898.75
Solving time	1.84	0.08	0.06	0.27	0.08	0.08	0.13
Sniffer Dogs	0	5	3	3	5	2	5
Specialized Security Marshalls	7	9	8	12	9	6	10
Normal Security Marshalls	42	40	48	46	51	35	55
Bomb-ble Bees	4	6	5	5	4	4	3

This table shows the results of Bomb-ble bees being implemented using Implicit Formulation. The table shows the optimal personnel costs, solving time, total number of Sniffer Dogs, total number of specialized Security Marshalls, the total number of normal Security Marshalls and the total number of Bomb-ble Bees for each day of the week.

Part-timers Implementing part-timers is not very effective for decreasing the costs. This can be seen by comparing the optimal personnel costs in table 5 with table 3. The costs are the same or a bit lower per day. However shown in table 5 there is a possibility to schedule a lot of part-times. This can be useful if there is a high demand for part-time working.

Table 5: Implementing part-time marshalls using Implicit Formulation

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	10430	10620	11615	12610	12900	9110	14120
Solving time	0.48	0.08	0.09	0.09	0.06	0.08	0.23
Sniffer Dogs	5	5	5	5	5	5	5
Specialized Security Marshalls	4	5	3	6	5	4	5
Normal Security Marshalls	25	24	30	32	26	22	27
Part-time normal Security Marshalls	16	19	17	16	28	14	32

This table shows the results of part-timers being implemented using the Implicit Formulation including Sniffer Dogs. The table shows the optimal personnel costs, solving time, total number of Sniffer Dogs, total number of specialized Security Marshalls, the total number of normal Security Marshalls and total number of part-time normal Security Marshalls for each day of the week.

Stricter breaks Comparing table 3 and table 6, we see that optimal personnel costs are higher for the risks flights when there are stricter restrictions for the break. On a weekly basis, this differs 2600 euros. This is approximately 135000 euros a year. This shows how important the flexibility of the breaks are for the personnel costs.

Table 6: Stricter restrictions concerning the breaks using Implicit Formulation

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	10720	11230	11865	13140	13520	9380	14180
Solving time	0.33	0.09	0.06	0.05	0.06	0.05	0.08
Total number of Sniffer Dogs	5	5	5	5	5	5	5
Total number of specialized Security Marshalls	4	5	3	7	5	4	5
Total number of normal Security Marshalls	40	40	45	46	47	32	49

This table shows the results when breaks can not be at the first or last 2 hours of a shift. The table shows the optimal personnel costs, solving time, total number of Sniffer Dogs, total number of specialized Security Marshalls and the total number of normal Security Marshalls.

Different demand We changed the data set for the normal Security Marshalls by increasing and decreasing the demand by one per period. Looking at the results (table 7) the optimal personnel costs differ between 650 and 720 compared to table 3. The model is therefore stable for these small changes, as we would assume that 36 shifts cost about 720 euros ($36 * 20$ euros).

Table 7: Change in demand per period by 1

+1	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	11110	11300	12295	13290	13590	9760	14840
Solving time	0.87	0.08	0.09	0.08	0.11	0.06	0.09
- 1	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Optimal personnel costs	9770	9960	10965	11930	12270	8430	13400
Solving time	1.95	0.06	0.09	0.06	0.08	0.06	0.19

This table shows the optimal costs for the problem when the demand for normal Security Marshall changes in every period by +1 and -1 respectively.

4 Conclusion and Future Research

This paper has used linear programming to solve labour-scheduling problems for a major Dutch Airport. To this end, a set covering formulation by Dantzig (1954) and an implicit formulation by Thomson (1995) were used and compared. Furthermore, several extensions were added, such as splitting the one hour break, adding dogs to sniff drugs and bees to search for bombs, adding part-timers and conducting some sensitivity analysis. For all these problems, the goal has been to find the cheapest labour-schedule for all the types of workers, consisting of normal security marshalls, special security marshalls who are required to handle dogs and bees, the dogs and bees themselves and part-timers. In finding these optimal solutions, it is clear that the Implicit Formulation leads to faster solving times. The extensions are not always connected and therefore have their own results. We found that Splitting the break into two smaller breaks does not make a big difference for the optimal personnel costs. Furthermore, including part-time shifts decreases the costs only a little bit, but increases the flexibility for the Security Marshalls. It also seems that although the Bomb-ble bees are a cheap way to detect bombs, their advantages (mainly their ability to replace dogs and work full days) are not sufficient to outweigh the extra costs brought on from checking for explosives. For the sensitivity analysis we changed some of the restrictions and demand. Adding stricter restrictions for the break leads to higher costs, however the shifts are more realistic. Small changes in the demand lead to expected changes in costs.

A limitation of our study is that the data concerning the Bomb-ble bees is not based on real bee-data. Another limitation is that we do not know the demand for other departure halls. Combining this data could lead to a better optimization of the Security Marshalls. Furthermore, weekly demand is assumed to have the same distribution throughout the year, while holidays and seasons can have an influence on the demand. Further research can possibly extend on these limitations.

5 Appendix

Table 8: All parameters for implicit formulation for all types

Parameters:	t=1	t=2	t=3	t=4	t=5
c_t: the cost per working period for a type t shift	20	30	5	1.25	20
mbl_t: number of periods in a meal break for a type t shift	2	2	0	0	0
$namb_t$: minimum number of post-meal-break working periods for a type t shift	1	1	1	1	10
$nbmb_t$: minimum number of pre-meal-break working periods for a type t shift	1	1	1	1	10
nl_t: minimum overall length of a shift in periods for a type t shift	12	12	1	1	10
$xamb_t$: maximum number of post-meal-break working periods for a type t	10	10	8	36	10
$xbmb_t$: maximum number of pre-meal-break working periods for a type t shift	10	10	8	36	10
xl_t: maximum overall length of a shift in periods for shift type t	17	17	8	36	10
ef_t: earliest possible finishing time for a type t shift	12	12	1	1	10
emb_t: earliest possible meal break starting time for a type t shift	2	2	1	1	11
lmb_t: latest possible meal break starting time for a type t shift	34	34	36	36	27
ls_t: latest possible starting time for a type t shift	25	25	36	36	27

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