De-peaking strategies for improving airport ground operations productivity at mid-sized hubs

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ABSTRACT

Today most large airlines operate using a hub and spoke strategy. At hub airports the hub carrier attempts to optimize its flight schedule to minimize passenger transfer times for connecting flights. The result is a high number of flight arrivals and departures during the peak periods but only a few movements in off-peak periods. This imbalance means that infrastructure and personnel are used inefficiently. De-peaking, which consists of spreading flights more evenly throughout the day allows airlines and ground handlers to use their resources more efficiently. De-peaking can also reduce energy consumption by reducing airport congestion.

While de-peaking has been applied successfully at major hubs to relieve congestion constraints, it has not been applied specifically to reduce costs and energy use. Therefore, the goal of this research was to evaluate the cost savings potential of de-peaking. The research focuses on cost savings for the ground handler since obtaining airline data would have been very difficult given the highly competitive state of the industry.

The research evaluated several de-peaking scenarios using data from the Zurich Airport. The research shows that de-peaking reduces the extreme workload peaks enabling staff and equipment to be used more efficiently and thereby reducing costs. The results for Zurich Airport show that a small amount of schedule adjustment can reduce ground handling costs by about 8 percent. Under the maximum schedule adjustment scenario, de-peaking could reduce costs by up to 20 percent. The research can be extended to include additional peak-oriented costs such as airline company costs and costs of energy as well as revenue impacts of reduced flight connectivity.

Keywords

Airport operations, Scheduling, De-peaking strategies, Productivity, Hub airports, Airline operations, Airport capacity

1. INTRODUCTION

Airline deregulation and the subsequent introduction of low cost carriers (LCC) have made the airline industry extremely competitive. The reduction in travel caused by the 2001 terrorist attacks in New York pushed several major airlines into bankruptcy and after several years of relative success, the recent rise in fuel prices have created extreme pressure on the industry. These influences have made efficiency even more important for airline success.

Traditional network-carriers suffer under the impact of Low Cost Carriers (LCC), which undermine the hub-and-spoke system. Clearly, new strategies are needed to optimize efficiency and to reduce cost penalties of traditional network carriers.

In the 1980s, network-carriers organized and structured their operation and schedule in a hub-and-spoke structure. In this structure, one or more airports, the so-called hubs, serve as connection points for passengers. The hub-and-spoke system enables these larger network carriers to provide service on many different origin-destination pairs. There are two different scheduling strategies that can be applied in hubs depending on the airport's infrastructure capacity and its efficiency.

In the first strategy, aircraft arrivals and departures are coordinated and grouped. In this strategy airlines try to maximize the number of short connections between popular and high-revenue generating cities. However, this banked-hub strategy reduces the efficiency of aircraft, airport and employees because aircraft must wait on the ground for connections and staff is under-utilized in the off-peak times.

The second strategy, known as continuous or rolling operations, tries to improve operational efficiency by scheduling arrivals and departures such that there is a constant flow in the hub throughout the day. In this strategy, aircraft and staff are scheduled such that ground time is reduced and well distributed throughout the day, thus reducing under-utilization in off-peak and congestion during a peak. In continuous operation, many short connections are lost resulting in longer connection times for passengers *(1)*. However, it is still possible to optimize connections with maximal revenue potential by careful scheduling to keep them attractive under rolling operations. Furthermore, researchers believe that many passengers will accept small increases in travel times *(2)* and their improved reliability that can be achieved through the use of rolling operations. The introduction of rolling operations at a hub is de-peaking.

In 2002, American Airlines decided to de-peak schedules at their two main hub airports Chicago O'Hare (ORD) and Dallas/Fort Worth International Airport (DFW). Applying the new de-peaked schedule, efficiency was improved and fewer aircraft and gates were used *(3)*. Also schedule reliability increased and waiting time in queuing and circling decreased. However, as a consequence, average and median transfer time increased by 7-10 minutes. This resulted in less attractive connections, a loss of market share and thus a decrease in revenue. Zhang et al. *(4)* estimated, that American Airlines lost about 4 percent of their market share at ORD due to de-peaking.

In 2004, Lufthansa introduced a de-peaked schedule for Frankfurt airport (FRA). In this case Lufthansa used iterative stochastic simulation to evaluate different schedules. In the final de-peaked schedule, 35 out of the 50 most profitable connections had a shorter overall travel time in comparison to the original schedule. The new schedule was also more reliable and as a consequence fuel consumption could be reduced by more than 70,000 tons annually *(5)*.

These two examples show that de-peaking can reduce costs both through much higher personnel and asset utilization and also through reduced fuel consumption. On the other hand, this type of rolling operations throughout the day could reduce revenues if market share in profitable connections decreases due to unfavorable connections. However, at mega-hubs as ORD, DFW or FRA, frequent connections on main and profitable routes could be offered to minimize these revenue losses.

In contrast, at medium sized hubs, it may not be possible to offer frequent connections on all main routes. Therefore, the questions are:

- Can medium sized hubs de-peak such that the savings benefits outweigh the decrease in revenues?
- How can this potential revenue loss be minimized?
- What savings are possible for airport ground handlers and what is their contribution to making their hub carrier more efficient?

Ultimately the target and challenge for all actors is to combine the revenue advantages of traditional banked hubs with operational efficiencies for continuous, de-peaked schedules.

In the next section, the actual situation at Zurich Airport, which is used as example for the study, is described. In section 3, the airport operations and relevant processes are briefly described. In chapter 4, the model to calculate the cost savings due to de-peaking is introduced. The cost savings are then illustrated for several de-peaking scenarios for the Zurich Airport example in chapter 5. And finally, conclusions are presented in chapter 6.

2. ZURICH AIRPORT OPERATIONAL DESCRIPTION

Zurich Airport (ZRH) is a typical mid-size airport. It serves around 40 different airlines and is the main hub for Swiss International Airlines. The airport has three runways in total (see figure 1), which allows a maximum of 66 movements within one hour. In 2006, 19.2 million passengers used Zurich Airport; 53.3 percent of these were on Swiss International Airlines. A total of 32 percent of all passenger used Zurich for a connection.

Ground operations in Zurich are mainly executed by Swissport. The airport has three passenger terminals with a total of 65 gates of which 56 are in operation and 25 additional gates for buses, which serve about 100 open stands. Swissport has around 2,200 employees in Zurich.

In 2006, Zurich Airport had a total of about 271,000 aircraft movements. During a typical day in the summer 2006 flight schedule, there were 521 landings and departures, of which 315 were by Swiss International Airlines. The temporal distribution of arrivals and departures of flights handled by the ground operator Swissport is presented in figure 2. Figure 2 shows that the hub is operated in a typical bank structure. As outlined earlier, this causes inefficient and cost-intensive under-utilization of staff during off-peaks for both the hub airline and the ground operators.

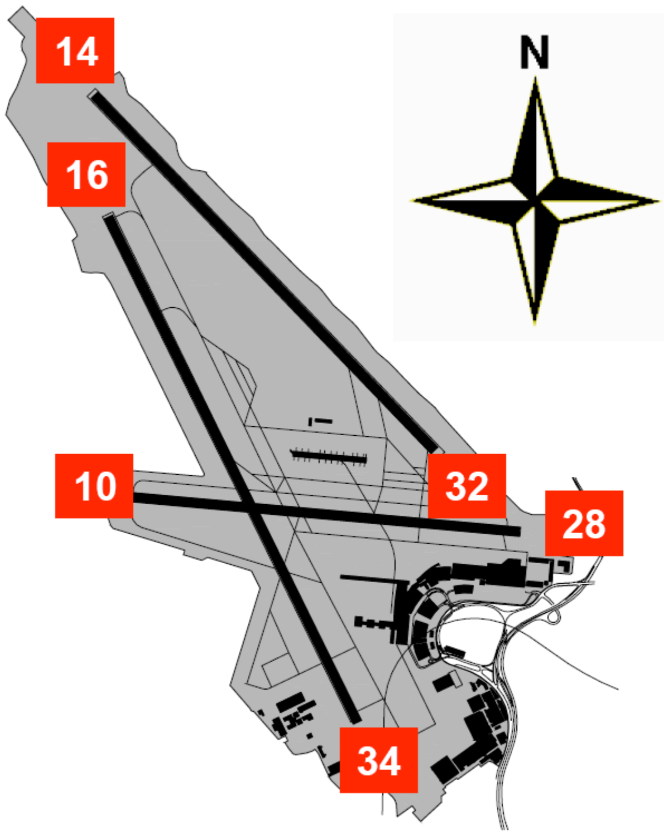

FIGURE 1 Infrastructure at Zurich Airport.

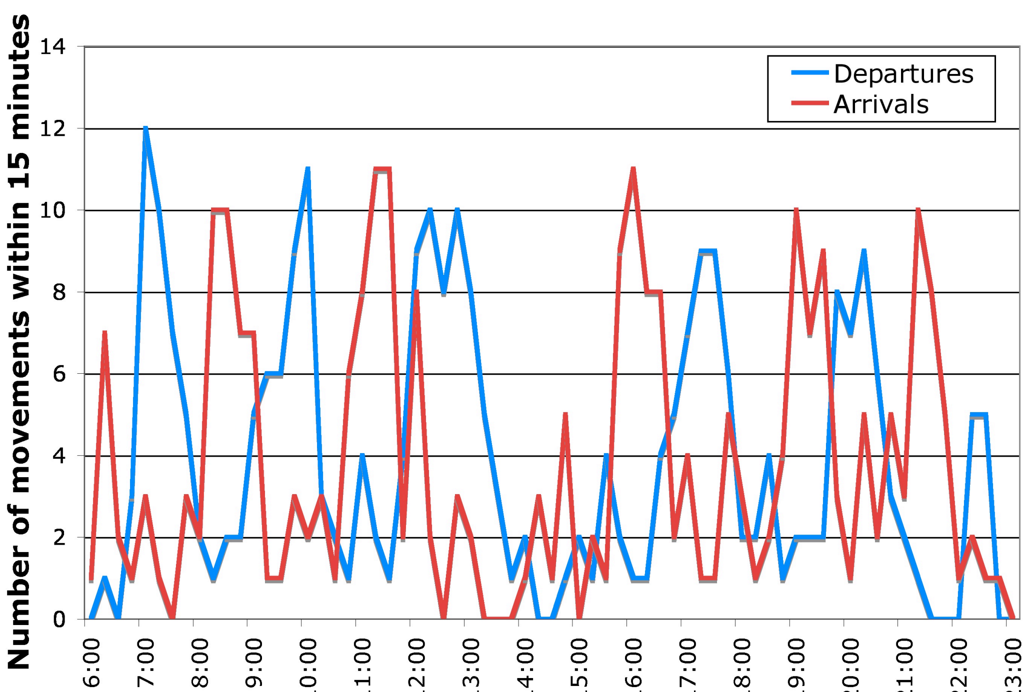

FIGURE 2 Distribution of arriving and departing flights at Zurich Airport handled by Swissport.

The discussion of de-peaking advantages presented above focuses on the airlines, however, de-peaking also provides similar benefits to the ground operations companies. Today, Swissport's ground operations staff are underutilized in non-peak periods and overloaded in peak periods. While precise scheduling of ground staff can help reduce these problems, if ground operations staff are too precisely scheduled then they will not be able to respond to airline operating delays effectively, thus causing additional delays and unsatisfied customers.

Given the highly competitive nature of the airline business, it is very difficult to obtain airline scheduling and marketing data. Therefore, this research used data from Swissport to evaluate the impact of various de-peaking strategies on ground operations. This is only a small segment of the potential savings that could be obtained through de-peaking; other savings would accrue to the airline companies (through more efficient and balanced use of their own staff), other airport peak-demand oriented services (e.g. customs inspection), and, importantly, reduced fuel use (including environmental and cost benefits). We recognize that de-peaking would have revenue impacts on airlines, but these could also be added to the model. In summary, this research developed a model that uses available data to quantify one aspect of the savings possible from de-peaking; the model can be extended to include additional costs and revenue impacts in further research since the initial results were promising.

3. AIRPORT GROUND OPERATIONS PROCESSES

A model was developed to evaluate the impacts of different de-peaking strategies on ground operations processes. The model was based on the resources needed by ground operations to service a specific type of airplane arrival and departure. The activities involved in servicing aircraft can be divided into processes, which consist of specific tasks. This section outlines the ground services processes and tasks, then describes how the model was developed.

3.1 Ground operations processes at hub airports

Ground operations processes can be divided into three main categories: passenger oriented, luggage oriented and airplane oriented. These processes are illustrated in figure 3. As shown in figure 3, two processes are located at the interface between process categories: the gate process is located at the interface between the passenger-oriented and airplane-oriented processes, and the ramp process is located at the interface between luggage-oriented and airplane-oriented processes.

The passenger-oriented processes begin either with check-in or leaving the aircraft. Zurich airport offers three different check-in areas where Swissport is active. One is designated for Swiss International Air Lines and its partners (check-in 1) another is for other carriers (check-in 2) and one is mainly for charter carriers (check-in 3). Normal check-in procedures are available at all locations. Special check-in such as group check-in or check-in for First class passengers is only available at check-in 1. After check-in passengers and luggage go different ways to the airplane.

A local passenger can go directly to the gate or make use of different services at the airport. Swissport provides special care assistance and frequent flyer or premium lounge/club services for its customers. Also transfer services are available. Transfer services are only used by passengers arriving without the boarding pass for their connecting flight. Normally transfer services are most important when connections are broken due to delays or flight cancellations. Both departing and connecting passengers make use of the gate services as they board the plane.

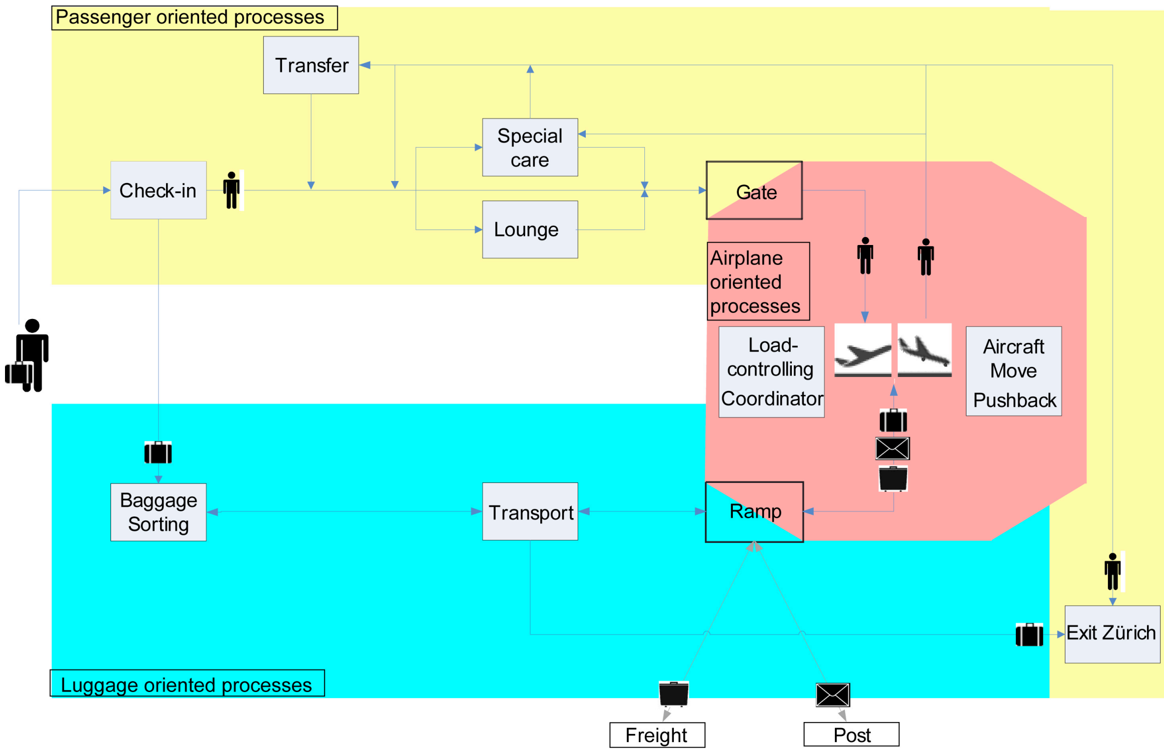

FIGURE 3 Ground operations processes at hub airports.

The luggage-oriented processes begin when the passenger provides luggage at check-in or the luggage is unloaded from an arriving airplane on the ramp. The luggage goes from check-in through the baggage sorting system and is transported to the plane where ramp will load it into the airplane. The processes are the same for offloading, but baggage with the destination Zurich is brought directly to the belt by transport and will not use the sorting system. Mail and cargo are brought on separate processes to the ramp, but then are loaded by the ground handler. Finally, passengers and luggage meet at Exit Zurich where passengers can take their luggage from the belt and proceed to customs, and onward to the exit.

The airplane-oriented processes include the aircraft move / pushback as well as the load controlling which is done by the "coordinator." The coordinator plans the load as well as the arrangement of the load in the plane. This function usually doesn't impact the passenger or the luggage. As the name indicates, coordination of different services is the main issue, whether the service is provided by the ground handler itself or another company (catering for example). Coordinators also are responsible for moving the jet way and therefore are involved in some arrivals as well as departures.

3.2 Production planning and standards

Each ground operations process consists of several specific tasks; each of these tasks requires personnel and equipment. Airlines and ground operations companies work together to develop production plans (or standards) for each task. These plans define the personnel and equipment needed over time for specific operations. Production standards depend on the airline, airplane and whether the airplane is arriving or departing. They are described relative to the time before departure or after arrival. Production standards define exactly how many people of each position and what equipment is needed at any particular time.

In this research three categories of airplanes (widebodies, narrowbodies and commuters), were defined and typical production standards were developed for each of these airplane categories. These production standards were defined in 5-minute intervals for both personnel and equipment requirements. Since the processes for arriving and departing planes and the time needed for these operations differ, a total of six production standards were developed and used in the model, two for each airplane category (a departure and an arrival). Figure 4 illustrates the production standard for a departing wide-body airplane.

Time [min] before departure	-65	-60	-55	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10
Gate Staff	0	1	1	1	1	2	2	3	3	3	3	3	3	3	3	0
Coordinator	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0
Pushback Driver	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Ramp Supervisor	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Ramp Staff	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0	0

FIGURE 4 Example of production standard (staff scheduled in 5 minute time steps) for a departing wide-body airplane.

The six production standards are a simplification of real conditions since it is not always easy to put a specific plane into one of the categories. For example, in the model commuter planes are assumed to use remote stands, but in reality they can also use gates with a jet bridge, which changes the specific tasks used to complete the ground operations processes. Nevertheless, the six production standard categories provided a good estimate of resources needed for the de-peaking assessment model.

The model used costs for the required personnel to estimate the cost of each of the six categories of operations.

In addition to personnel, every process uses specific equipment, which also must be considered in the analysis. The following equipment was included in the model and specified in the 5 minute time step production standards:

- General Power Unit (remote stands)
- WLAN car (for coordinators on remote stands)
- High loader
- Conveyor
- Container lifting transporter
- Container transporter
- Passenger step
- Pushback-Truck

In order to evaluate the costs for equipment, the model estimated the amount of equipment needed and applied an average annual cost for each piece of equipment.

Finally, it should be noted that consumable material does not need to be taken into account, since the number of flights and passengers has been kept constant, only their distribution over the day varies based on the de-peaking scenario.

3.3 Peaking relevant processes

It is important to recognize that all the activities of ground operations companies are not impacted to the same extent (and some are not impacted at all) by de-peaking. Therefore these activities were left out of the de-peaking scenario evaluation model.

One set of activities not impacted by de-peaking are those already staffed for average passenger demand. These types of activities do not correlate exactly with aircraft arrivals and departures. These activities include:

- Lounge services;
- Special care assistance;
- Transfer services, (workload depends on weather/special events rather than scheduled operational peaks); and
- Arrival services (Exit Zurich such as services for damaged or missed luggage).

Another set of activities not included in the model was baggage handling. Baggage handling could not be included since baggage is handled by a different company (Swissport Baggage Systems) and furthermore, the luggage of Swiss and its partner airlines could not be divided from the other baggage.

Finally, the model did not consider check-in services. Although check-in services are traffic constrained and thus should be kept in the analysis, the problem is that other factors such as destination, amount of baggage, land side public transport schedules, airline departure time or the airline itself have a significant amount of influence on the time of check-in for a specific flight. Therefore, the load curve was too inhomogeneous for a general description.

In summary, only the airplane oriented processes were included in the model. Specifically, the gate with gate workers, the load planning with coordinators, the aircraft move with the pushback drivers and the ramp with supervisors and ordinary ramp workers. Nevertheless, the calculated saving potentials could also be applied and transferred to other types of airport activities, which were not modelled in this research.

3.4 Swissport scheduling principles

Swissport schedules personnel based on the expected workload, a function of the number of passengers and flights. Scheduling is based on the production standards described in Section 3.2. Swissport estimates the number of personnel needed for each task and develops the "task demand." Figure 5 illustrates the task demand for a typical day. As shown in the figure, the task demand varies enormously during the day and clearly shows the peak and off-peak periods.

Once the task demand is known, Swissport can schedule the specific personnel needed to accomplish the tasks, this is called the "shift demand." The assignment of staff depends on their skills (multi skilled staff can be used more flexibly). The staff shifts vary, but Swissport does not operate with "split shifts," two short shifts with a long break in-between. Figure 5 also shows the shift demand for a typical day.

As Figure 5 illustrates during peak periods of the day there is greater task demand than staff capacity (work overload), while during non-peak periods staff are underutilized. The goal of the de-peaking exercise is it to rebuild the task demand curve so that it remains under the shift demand. Of course building a perfect schedule (one in which task demand was exactly matched with shift demand) is impossible, given the staff and shift length constraints. However it is possible to improve efficiency to some degree. Similar to the personnel requirements, the demand for equipment also has strong peaks and valleys. Therefore, de-peaking can also reduce the amount of equipment needed at an airport.

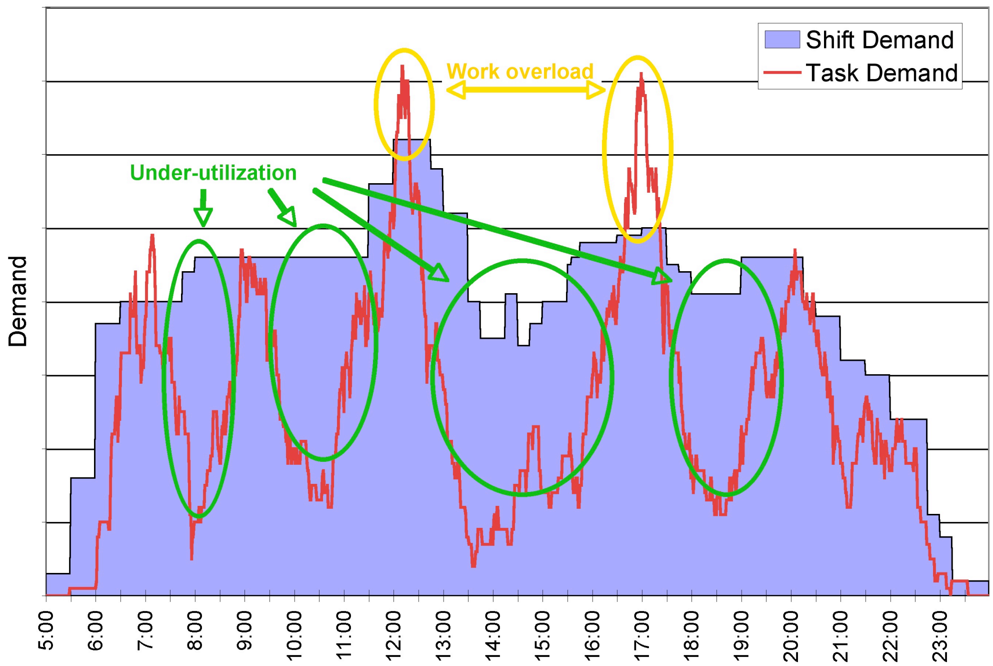

FIGURE 5 Shift demand and task demand for a typical day (data based on historical flight schedule and demand data by Swissport).

Two important factors in scheduling ground operations staff (besides task demand) are the length and starting time of shifts. Since Swissport schedules staff using dozens of different shift lengths, the model categorizes shifts into two categories. Every shift with a length of more than 6 hours is considered long, the rest are considered short. For the ground services operator it is important what type of shift is being eliminated; only short, only long or some of both shift lengths.

4. DE-PEAKING STRATEGIES

Schedules can be de-peaked to varying degrees. The amount of de-peaking has consequences on the schedule as well as on the ground operations workload and equipment requirements (which depend on the schedule). Figure 6 illustrates various levels of de-peaking schematically. The top section of Figure 6 shows a typical schedule with several peaks of differing magnitude spread throughout the operating day.

A fully de-peaked schedule would have airports operating with a constant number of arrivals and departures throughout the day. This would be the ultimate in de-peaking and it is illustrated by the red line in the second section of Figure 6. The schedule in such a scenario is completely different from today, since there are no peaks. Under this scenario, passenger flight connectivity decreases dramatically although it would still be possible for the hub airline to maintain some important connections. This strategy is unrealistic from today's business perspective, but has been analyzed in the research to estimate the maximum benefit of de-peaking.

Since a fully de-peaked schedule is unrealistic, reduced levels of de-peaking were also evaluated in the research. The key variable in determining the level of de-peaking is the maximum amount of time that an aircraft arrival or departure can be shifted in the de-peaking process. As the maximum amount of time increases, the level of de-peaking also increases, but the passenger flight connectivity decreases. The bottom two parts of Figure 6 show two types of de-peaking scenarios. The third section shows a scenario where peaks are reduced to a specified maximum level; this results in relatively large schedule changes. The bottom section shows a scenario where all peaks are reduced by approximately the same percentage; this requires a smaller amount of schedule change.

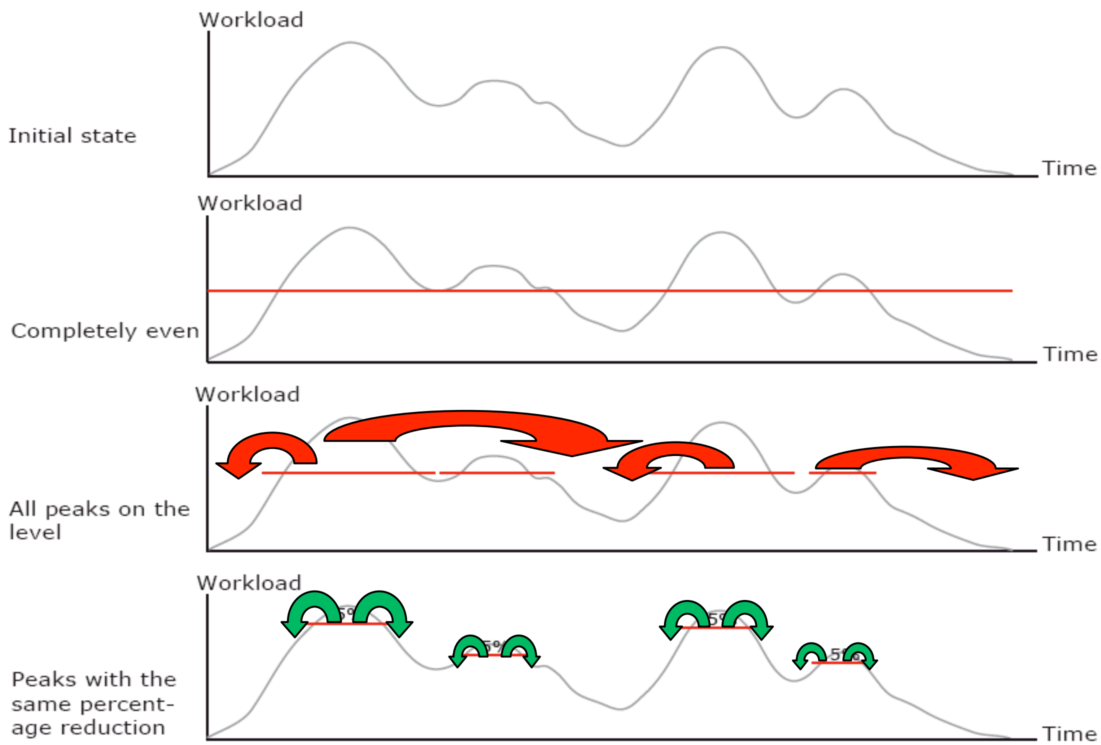

FIGURE 6 De-peaking strategies.

This last scenario, de-peaking by making relatively small changes in flight schedule, is the only realistic alternative in today's highly competitive air travel market. In this scenario flights are only shifted slightly from their original schedules and more connections are maintained.

The independent variable to be tested when evaluating different de-peaking scenarios is the maximum amount of time shift allowed for rescheduling. If flights are allowed to be shifted a maximum of 15 minutes ahead or behind its scheduled departure or arrival time, the main peaks will remain high. On the other hand, allowing flights to be shifted +/- 60 minutes can reduce the peaks, but significantly change the original schedule. Since maintaining connections is a key goal for hub airlines, a 100% de-peaked schedule is unrealistic from a business perspective (however, it will be considered in the analysis to estimate the maximal possible cost savings possible through de-peaking).

5. RESULTS FOR THE ZURICH AIRPORT DE-PEAKING CASE STUDY

5.1 Optimization procedure

The ground operations cost model was used to evaluate the following three alternative scenarios

- Scenario 1 – a de-peaking scenario allowing only small arrival/departure schedule shifts (maximum shift of 30 minutes);
- Scenario 2 – a de-peaking scenario allowing relatively large schedule shifts (up to 60-minutes); and,
- Scenario 3 - a full de-peaking scenario.

The estimated costs of these scenarios were then compared to the current cost to determine the impact of de-peaking.

The calculation in the ground operation cost model starts with the original flight plan. Thereby, the production standards for all resources and all movements were summed for each 5-minute time step. Next, the personnel shifts were distributed throughout the day. Consequently, times with overload of work and under-utilization occur. Depending on the scenario, the maximum shift for arrivals/departures (30-minutes, 60-minutes and no maximum for the full de-peaking scenario) was set as a constraint for the algorithm.

After defining the initial state, a genetic algorithm was used to optimize the schedule and minimize costs. The cost function used by the algorithm was the total amount of under-utilization. Simultaneously, the algorithm was developed to prevent overload of any resource. The under-utilization was summed up for each time-step and each resource and then weighted by their specific costs.

The genetic algorithm had two parameters to change: first the point of time an aircraft arrives or departs and second the point of time the shift starts for each worker. The genetic algorithm then calculated various schedules as solutions.

Finally, the calculated schedules were checked for their feasibility. A schedule was considered not feasible and was eliminated if overwork occurred (i.e. the number of tasks at any point of time, which is equal to the summation of all production standards by all flight movements, was larger than the available staff or equipment). Schedules that were not feasible were eliminated.

If the algorithm generated a feasible schedule, the amount of staff and equipments was reduced to optimize production costs. Subsequently, the genetic algorithm was re-run with the new staff and equipment levels. This procedure, illustrated in Figure 7, was repeated until no valid solution was obtained. The last feasible solution then is the cost-effective schedule by the given constraints, minimizing under-utilization in the off-peak period and avoiding overload during peaks.

As outlined above, the model was based on data provided by Swissport and thus limited to ground handler processes. The general optimization procedure to evaluate the de-peaking effects and possible savings could easily be extended to various other processes. This would only require defining production standards for the additional processes. The model could also be extended by developing more detailed production standards e.g. for more aircraft types or differences between carriers.

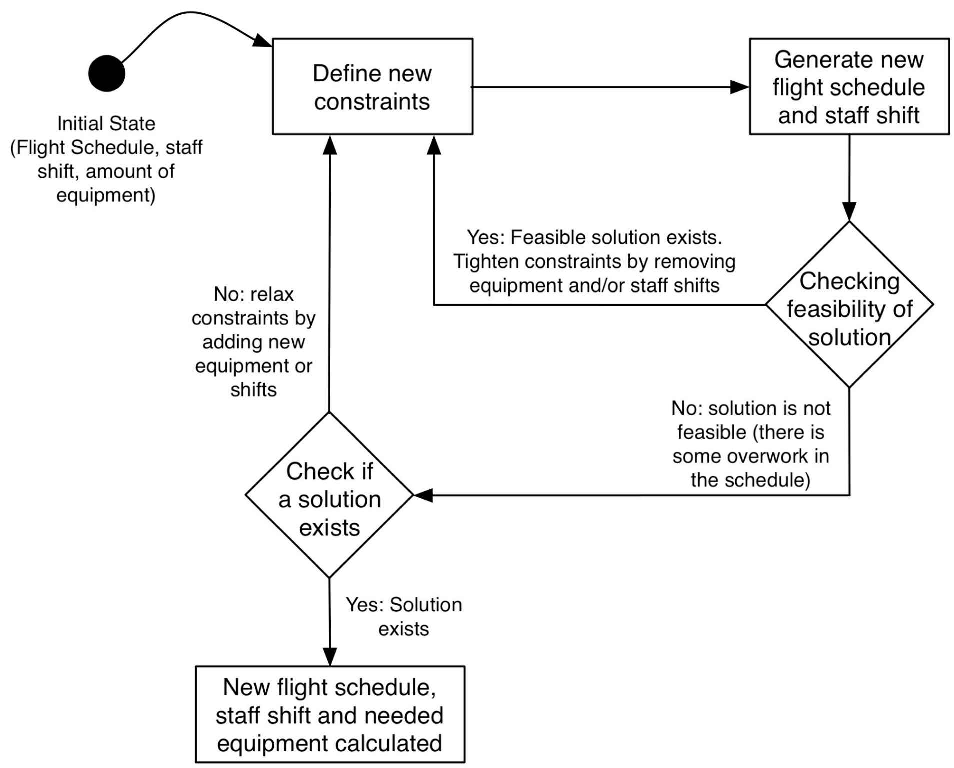

FIGURE 7 Procedure to calculate new schedules and minimal costs.

5.2 Specific results for the Zurich Airport Case

Analysis results are presented in Table 1. As shown, for the slight de-peaking scenario (30-minute arrival/departure time shift limit), ground operations costs could be reduced by 7.8 percent from the existing schedule. For scenario 2 (maximum 60-minute schedule shift), costs could be reduced by 10.8 percent, which is not much larger than for the scenario with a 30 minutes shift. In the full de-peaking scenario, ground operations costs could be reduced by approximately 20.3 percent. Doing a separate consideration for equipment and workforce, in all cases relative savings (in relation to the initial costs) on equipment costs were larger than workforce savings. Although in absolute terms, workforce savings are about ten times larger than capital savings.

These results are only about half as large as those obtained in a study of another mid-sized European airport *(6)*. This is a consequence of the fact that in the study by Kemppainena, the peaks were more pronounced than in the Zurich case and average workload was relatively small. Furthermore, Swissport operations are already quite efficient since they allow temporary overload of work. This reduces the potential cost savings from de-peaking since overwork was not allowed in the scenarios modeled in this research.

Activity	Original Schedule	Scenario 1	Scenario 2	Scenario 3
Maximal shift of movement	No shift	30 minutes	60 minutes	No Maximum (full de-peaking)
Relative workforce costs	100 %	92.3 %	89.2 %	79.8 %
Relative capital (equipment) costs	100 %	91.6 %	89.2 %	78.3 %
Total relative costs	100 %	92.2 %	89.2 %	79.7 %

TABLE 1: Overview of relative cost for different de-peaking scenarios

Figure 8 highlights the differences between the original schedule and the developed de-peaked schedule with a maximal 30-minute shift in arrival/departure time. It is clear that the flights were shifted only slightly and that peaks were reduced by only one or two movements. However, the results illustrate clearly, that even small changes in the schedule can have a significant impact on costs and offer a considerable potential to improve efficiency.

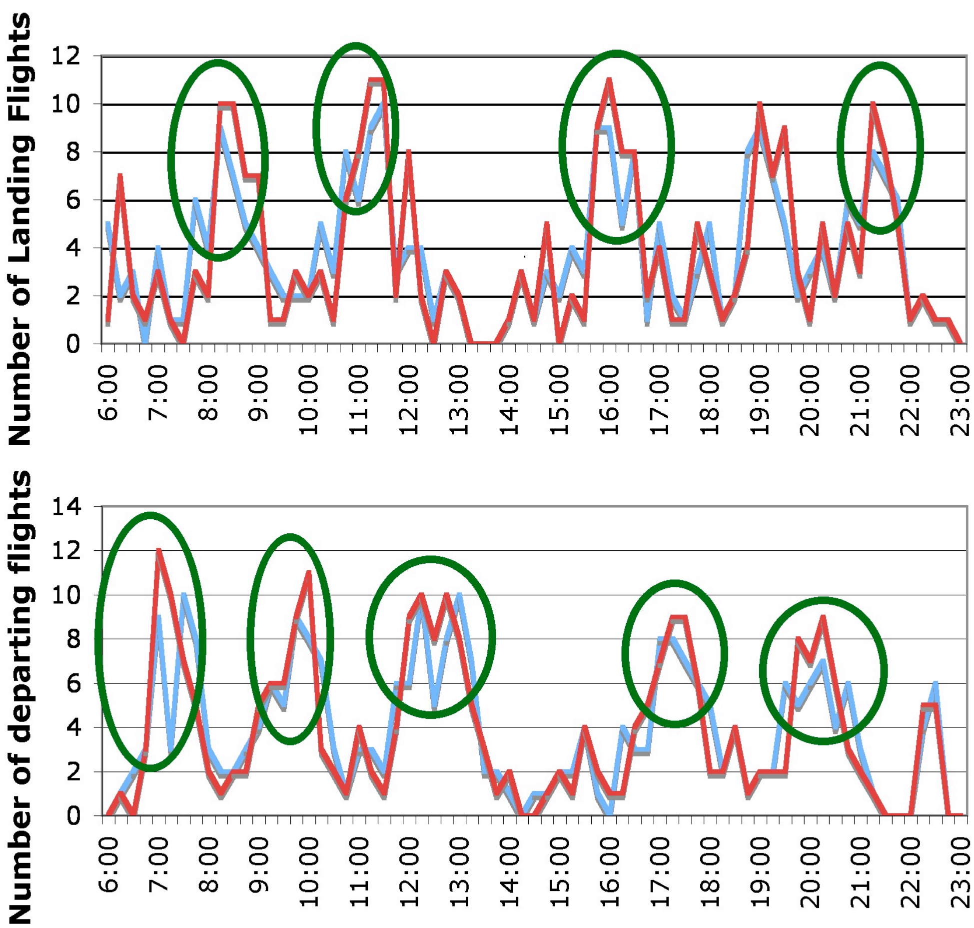

FIGURE 8 Comparison of flight movements for original (red) and de-peaked schedule (blue); reduction of peaks are highlighted (green).

While it is clear that even a small amount of de-peaking can reduce ground operations costs significantly it is important to recognize several assumptions. First, the model evaluated a typical workday, the level of peaking and the hourly costs are different for weekends and holidays so the impact of de-peaking on costs for these days would be different. Second, only tasks close to production were analyzed in the model. Administrative tasks, independent from the schedule, were neglected and offer no saving potentials.

Finally, the study only considered costs for the ground handler. However, it can be assumed, that de-peaking can also reduce costs for the airport operator, the hub-carrier and closely related companies. It can also reduce the amount of fuel burned by aircraft both on the ground and in the air due to delays caused by congestion at peak periods (it also reduces environmental impacts by reducing fuel burn). On the other hand, the hub-carrier has to analyze in detail, if such a de-peaked schedule is feasible for its operations and if the potential cost savings outweigh the impact on revenue due to worse connections.

6. CONCLUSIONS

This paper has analyzed the potential savings achievable by de-peaking a banked hub for a typical mid-sized airport. A model to estimate the saving benefits and different de-peaking strategies was introduced. The study results show that shifting schedules only slightly can reduce ground operations costs by almost 8 percent and can eliminate overload of work for ground staff. Consequently, even small changes in the schedule offer major benefits through more efficient operations, less under-utilization and higher productivity. A complete de-peaking of operations (constant number of aircraft movements throughout the day) offers the possibility to increase the savings of up to 20 percent, but is unrealistic from a business standpoint.

The research results show that even small changes offer significant saving potential. Higher efficiency through a de-peaked flight schedule strengths the position of both the hub carrier and the airport. This is especially true if the hub airline combines de-peaking with detailed schedule planning to reduce connection times for high revenue origin-destination pairs.

The research shows that de-peaking could be a valuable strategy for improving air transport operations. While this study focuses on a single aspect of the system (ground handling operations), it demonstrates that even within this limited area substantial cost savings are possible.

The research could be extended in two ways. First, the model could be modified to include additional "peak demand" costs such as aircraft delay (on the ground and circling in the air), baggage handling and airline staffing. This could also include the environmental benefits for a reduction in fuel burning. Furthermore, a model for estimating revenue impacts of changes to flight connectivity could be added to the general model. Also, more precise production standards to differentiate more aircraft types or carrier company could be developed. Second, the model could be automated to evaluate different schedule shift scenarios to identify the optimal number of minutes for shifting. This would also help model more precisely the influence of peak magnitude in the original schedule on possible savings through de-peaking.

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