Research of the relation between the sustainability of hourly capacity at Schiphol airport, KLM arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection

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Abstract— **Schiphol airport has become one of the major airline hubs in Europe as a result of KLM's growth strategy in the 1980s and 1990s. To provide a high customer satisfaction level, it is of great importance for KLM to provide a highly reliable network. In this paper two performance indicators (PI) are identified to express this reliability: the arrival punctuality according to the KLM timetable and the percentage of KLM transfer passengers at risk of loosing their connection.**

This research addresses the effect of the performance of the Dutch air navigation service provider (Air Traffic Control the Netherlands – LVNL) on the arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection. The contribution of LVNL is expressed in hourly inboud capacity and delays caused by its reduction as well as in terms of the LVNL performance indicator – sustainability of hourly capacity.

The study has shown that there is a linear relation between the sustainability of hourly capacity, KLM arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection. The relations are derived from the historical data and they are limited to KLM European inbound flights in the second bank of the day (based on the 7 banks system KLM is operating with) when two landing runways were in use. These are made based on sustainability value calculated for the given declared capacity. The derived models can be used for making estimations of arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection for a given sustainability. The estimate values have been compared with the actual ones and have shown that the actual values lay well within the confidence interval of the models demonstrating the accuracy of the models.

Furthermore, the effect of a reduced hourly inbound capacity on arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection has been researched. When the capacity forecast value is higher than demand at Schiphol, LVNL induced delays are low. Values of arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection are almost constant for small values of the LVNL influenced delays and therefore do not fluctuate much when the capacity forecast is higher than demand.

The relationships found lay the basis for decisions support models and tools for optimizing and further developing the KLM network operations at Schiphol airport.

Keywords: Schiphol airport, KLM, ATC the Netherlands, LVNL, arrival punctuality, transfer passengers, sustainability of hourly capacity, hourly inbound capacity.

I. INTRODUCTION

KLM has about 11 million passengers each year arriving at Schiphol as one of the major European hubs. About 70% of them are transfer passengers. To serve these transfer passengers, KLM must assure high quality connections at the Schiphol hub, providing a quick but reliable connection onto the next flight. To offer an attractive travel schedule to its passengers KLM designed its timetable to minimize the travel time between origin and destination through short connection times.

In order to maximize the number of high quality connections at Schiphol airport, KLM's timetable has been constructed into several arrival and departure waves or banks (see Fig. 1). The duration between scheduled arrival time and scheduled departure time of a connection should be at least the minimum connecting time (MCT). If it is shorter than the MCT, passengers cannot make a connecting flight and tickets for such connections cannot be sold.

As air travel demand increases, KLM faces the challenge to optimize and expand its hub operation at Schiphol airport as part of the competition between global airline alliances. To maintain and expand its market share KLM must offer more attractive connections through its hub at Schiphol. This growth of connectivity requires an increasing number of flights in arrival and departure banks. This increased peak demand leads to a saturation of airport capacity at the expense of increased

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arrival-delays, which in turn affects the reliability of connections which is vital to KLM's operation.

The development of KLM's network thus is determined by the balance between airport capacity and network demand. This capacity – demand balance governs both KLM's strategic[1] and tactical[2] decision making process. To optimize this decision making process it is necessary to relate factors which play a role in KLM's performance (such as arrival punctuality and the percentage of transfer passengers at risk of loosing their connections) to LVNL – factors (Air Traffic Control the Netherlands – factors, such as capacity forecast and sustainability) (see Table I).

This paper researches relations between performance indicators (PIs) of KLM and LVNL. The relationships established in the study are used as models for forecasting values of KLM PIs (arrival punctuality and the percentage of KLM transfer passengers at risk of loosing their connection (percentage of the KLM sub-MCT passengers, see Table I)) based on a given sustainability of hourly capacity (LVNL PI). This paper is the follow-up study of the paper from Ref. [1] and forms a basis for the tools which can help KLM in developing and optimizing its network at Schiphol.

II. DEFINITIONS

Table I gives a list of the definitions used in this paper.

TABLE I. LIST OF DEFINITIONS USED IN THIS RESEARCH.

	Definition
Arrival punctuality	The percentage of flights that arrived on time or earlier compared to the scheduled arrival time, i.e., SBA (at the gate).
Arrival delay	The difference in time between scheduled on-block arrival time (at the gate) according to the timetable (SBA) and the actual on-block arrival time (ABA), i.e., ABA-SBA. A flight that arrived earlier than or at the SBA is considered to be "on time". One minute late or more is considered to be "delayed".
FIR delay	A delay of a flight within the Dutch Flight Information Region (FIR). It is calculated as a difference between the actual time an aircraft flies[a] and taxies from FIR boundary until gate (ABA-FIR) and a sum of nominal flight and taxi times from FIR entry through specific sector to specific runway and from there to gate. [FIR delay= (actual flight time from FIR + actual taxi time from runway) – (nominal flight time from FIR[b] - nominal taxi time from runway[c])]
ATFM delay	A delay of the aircraft at the outstation caused by the reduced capacity at Schiphol airport.
Transfer passenger	A passenger with a ticket for the connecting flight, arriving at Schiphol on a KLM inbound flight and leaving Schiphol on an outbound flight of any carrier.
Minimum connecting time (MCT)	A minimum transfer time between the inbound and outbound flights a passenger[d] needs to make a connection to. Tickets can be sold only for the connecting flights with scheduled transfer time of at least MCT. For Schiphol, the MCT between both European inbound and outbound flight is 40 minutes, other connections have MCT of 50 minutes.
Sub-MCT passenger	A transfer passenger having an effective transfer time of less than MCT.[e]
Effective transfer time	The time difference between actual arrival time of the inbound flight and schedule departure time of the connecting outbound flight.
Capacity forecast	A number of landings per hour, which can be realized based on the expected availability of the runways (due to the weather conditions, maintenance of the runways and/or available staff). It is issued 4 times a day for the next 6 hours by LVNL (ATC the Netherlands).[f]
Demand	A number of planned landings (of all airlines) on Schiphol filed a day before their actual landing.[g]
Delta capacity	A difference between the capacity forecast and demand.
Declared capacity	A number of landings per hour that can be handled by the LVNL. It is determined for a longer period of time (year) and slot allocations are based on it. Declared capacity is 68 landings per hour for years 2006 and 2007.
Sustainability	A percentage of time a declared capacity is indeed realized by the providers (see Fig. 2).

[a] Actual flight time can be extended significantly due to the tactical flight management: vectoring (stretching the flight path) and/or use of holdings.

[b] Nominal flight time is calculated as a median value of the difference between the touch down time (TDT) and time of the FIR entry (FIR): Nominal flight time = (TDT-FIR)median. It is calculated for an undisturbed flight from each ACC sector entry until a particular runway.

[c] Nominal taxi time is calculated as a difference of the time the aircraft crosses the red line (the border between the platform and maneuvering area - it is considered in that case that the aircraft reached the gate) and the touch down time: Nominal taxi time = (time (crossing the red line) - TDT))aver. Only average taxi times are available at LVNL.

[d] It is assumed that the baggage of the passengers is transferred together with the passenger to the connecting flight.

[e] It is assumed that departure flights depart on time.

[f] It may differ from the actual capacity, but rarely and therefore gives a reliable indication of the capacity at Schiphol.

[g] Data are received from the Amsterdam Airport Schiphol (AAS) and KLM.

At this point it is important to underline that in this research the percentage of the sub-MCT passengers used differs from the actual percentage of passengers who cannot make their connections. Actual percentage of passengers who cannot make their connection is lower than the percentage of the sub-MCT passengers, because even if the passengers arrive with the effective transfer time smaller than the MCT, in some cases it is still possible to make their connections (such as: gates are close to each other, departing flight was delayed, passenger can reach the gate faster than assumed in the MCT value etc.). The percentage of the sub-MCT passengers is used here instead of the actual percentage of passengers who cannot make their connection to avoid a number of effects at the airport that cannot be influenced by the LVNL (such as: delays of the departing flights, delays in opening the aircraft doors etc.). Actual number of passengers who miss their connection is a result of a daily (tactical) handling of flights. It is not suitable for this research, because the results of the research will be used for the strategic development at Schiphol.

[1] *Strategic: referring to KLM's network development process.*

[2] *Tactical: referring to the network management process on the day of operation.*

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III. Relations between the hourly inbound capacity, LVNL- influenced delay, sustainability of hourly capacity, arrival punctuality and percentage of the sub-MCT passengers

The aim of this paper is to research the relation between the important performance indicators (PIs): sustainability of hourly capacity (as an LVNL PI) and arrival punctuality according to timetable and percentage of the sub-MCT passengers (as the KLM PIs) (see Fig. 3(a)). Hence, it is needed first to better understand the relation at a lower aggregation level, i.e., between the LVNL –factors, arrival punctuality and percentage of the sub-MCT passengers (see Fig. 3 (b)).

As LVNL-factors are considered:

- Delays influenced by the LVNL (Dutch ATC), i.e., the delays at outstation caused by the reduced capacity at Schiphol airport (ATFM delays) and delays within the Dutch FIR (FIR delays) (see Table I) and
- Hourly inbound capacity. Hourly inbound capacity consists of the capacity forecast and delta capacity (see Table I).

Research is limited to:

- KLM European inbound flights connecting to outbound flights of KLM or any other carrier. European inbound flights are chosen because they can be regulated by the Air Traffic Flow and Capacity Management (ATFCM) restrictions and therefore the impact of LVNL is higher on them;
- summer 2006 and winter 2006/2007 (7 banks system) (see Fig. 1 (a));
- arrival bank 2 (see Fig. 1 (a)). This bank has been chosen, because demand of the flights in the core of the bank is close to the maximum inbound capacity. Moreover, this bank does not suffer from the snowballing effect (flights in the later banks can be delayed as a consequence of the accumulated delays during the day);
- the periods when two landing runways were in use and one runway was used for the departures (from about 7.30 until 9.15 LT);
- Sustainability values calculated by using the declared capacity value of 68 landings per hour.

The exact values on the axis in the graphs that follow are not given, because of commercial sensitivity of data for the parties involved in the research.

Fig. 4 shows delta capacity vs. capacity forecast for bank 2. From this graph the capacity demand (capacity forecast value when the demand is equal to the capacity forecast) is determined and it is the same in both seasons. Moreover, critical capacity and corresponding critical delta capacity for each season are denoted, because above critical capacity value, the percentage of the sub-MCT passengers will not change significantly (as will be discussed below).

Fig. 5 shows that as long as the capacity is higher than the demand, ATFM+FIR Delay stays rather low and nearly constant, which is in about 80-90% of time (depending on the season). In summer the percentage of time with capacity higher than critical one is higher due to the better weather conditions (and therefore fewer restrictions) than in winter. However, when the capacity drops below the critical value an increase in the ATFM+FIR Delay occurs. The increase shows stronger slope for the winter season, which can be attributed to more frequent capacity reduction. These graphs are not fitted, because the numbers of measurement points in the region below critical capacity are not enough to obtain a reliable fit.

Arrival punctuality and percentage of KLM sub-MCT passengers vs. ATFM+FIR Delay has been plotted in Fig. 6. It can be observed that the increase in the ATFM+FIR Delay causes the decrease in the arrival punctuality and increase in the percentage of sub-MCT passengers. For small ATFM+FIR Delay arrival punctuality as well as the percentage of sub-MCT passengers stays almost constant. The scale of both x-axis is the same. It can be noticed that for the same value of the ATFM+FIR Delay, the percentage of sub-MCT passengers increases rather slow whereas arrival punctuality decreases rather fast. This can be explained by the following: If the aircraft is even one minute delayed compared to the schedule, it is considered as delayed flight and it contributes to the reduction of arrival punctuality. However, a number of transfer passengers connecting to different outbound flights could be on this inbound flight. Therefore, the delay of the inbound flight does not mean that all passengers are under the risk of loosing their connecting flights. Only the passengers that arrive with the effective transfer time less than MCT are at that risk.

Fig. 7 shows arrival punctuality and percentage of the KLM sub-MCT passengers vs. capacity forecast and delta capacity. The arrival punctuality does not change significantly above the capacity demand value and for positive delta capacity (see Fig. 7 (a), (b)). Below the capacity demand value and when the demand is larger than the available capacity, arrival punctuality drops rather fast. Percentage of sub-MCT passengers behaves more inertly (see Fig. 7 (c), (d)): when the capacity is above the critical capacity and related critical delta capacity (see also Fig 4), the percentage of the sub-MCT passengers stays almost the same. Note that the unit on y-axis in Fig. 7 (d) is half of the values of the unit on y-axis in Fig. 7 (c). The explanation of this behaviour of the percentage of sub-MCT passengers is the same as for Fig. 6.

Percentage of sub-MCT passengers vs. arrival punctuality exhibits almost linear behaviour (see Fig. 8). Higher arrival punctuality results in low percentage of the sub-MCT passengers. Each data point corresponds to the arrival punctuality and percentage of the sub-MCT passengers for a period of 30 days using method of sliding window with a timeframe of one week.

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Relationships between dependences of the arrival punctuality and percentage of sub-MCT passengers vs. sustainability of hourly capacity are given in Fig. 9 (see also Fig. 3 (a)). Linear fits and the confidence interval are given and used as models to obtain the values for arrival punctuality and percentage of sub-MCT passengers for expected sustainability value. The models were tested for the bank 2 of summer 2007, because the same limitations to models apply to this period (see description of the limitations given above in this Chapter). Sustainability value for summer 2007 is estimated from the data available at LVNL [2]. Arrival punctuality and percentage of sub-MCT passengers values are estimated (forecasted) from the linear fit (see Fig. 9) for the estimated sustainability value and compared to the actual values for summer 2007. As it can be observed from the graphs, actual values for arrival punctuality and percentage of sub-MCT passengers are very close to the forecasted values and very well within the confidence interval. Hence, it can be concluded that this model can be used for the estimation of the arrival punctuality as well as percentage of sub-MCT passengers values and gives good results as long as the limitations to the model (given above in this Chapter) apply. In case that some of the conditions change (for instance, KLM changes the banks system from 7 to more, the model is applied to another bank of the day, sustainability is calculated for another value of declared capacity etc.) a new model has to be built.

IV. Conclusions and Outlook

Research has been conducted to relate important performance indicators (PIs) for KLM: arrival punctuality according to timetable and percentage of sub-MCT passengers, and LVNL performance indicator – sustainability of hourly capacity.

This high level research framework identified that a correlation is deducible between these PIs. Linear relations between them are found. The empirical models have been made for the KLM European inbound flights arriving in bank 2 when two landing runways were in use and when KLM has been operating with 7 banks system (summer ‘06 and winter ‘06/’07). The models were tested for summer ’07. It can be concluded that the actual values of arrival punctuality and percentage of sub-MCT passengers for estimated sustainability of hourly capacity for summer ’07 are close to the forecasted values and well within the confidence interval of the model. Hence, these models can be used for forecasting as long as the mentioned limitations apply.

Additionally, when the capacity forecast at Schiphol is higher than demand, low LVNL-influenced delays occur. Arrival punctuality and percentage of sub-MCT passengers are almost constant for small LVNL-influenced delays. It is shown that arrival punctuality and percentage of sub-MCT passengers do not fluctuate much when the capacity at Schiphol is higher than demand. However, decrease in arrival punctuality and increase in percentage of sub-MCT passengers occur when demand exceeds capacity forecast values.

This research has been limited to bank 2. To apply it to the whole day, more research has to be done. This can be rather complex and results may not be easy to compare due to the snowballing effect of delays during the day and the difficulty of defining their exact cause.

The follow-up study will focus on the potential optimization of the scheduled flying time for each KLM flight by minimizing the effect of LVNL induced delays.

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References

[1] D. Mijatovic, M. Meert, K. El-Bachraoui, J. Wanga, “Research of the relation between the hourly inbound capacity at Schiphol airport and the number of KLM transfer passengers at risk of loosing their connection,” Proceedings of the 6th EUROCONTROL Innovative Research Workshop Bretigny, France, 4-6 december 2007.

[2] VEM Performance Standard Summer 2007 D/R&D/023, LVNL, Schiphol Oost, The Netherlands. (2007)

List of Abbreviations

AAS	Amsterdam Airport Schiphol
ACC	Area Control Centre
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
FIR	Flight Information Region
KLM	Royal Dutch Airlines
LT	Local Time
LVNL	Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)
MCT	Minimum Connecting Time
PI	Performance Indicator

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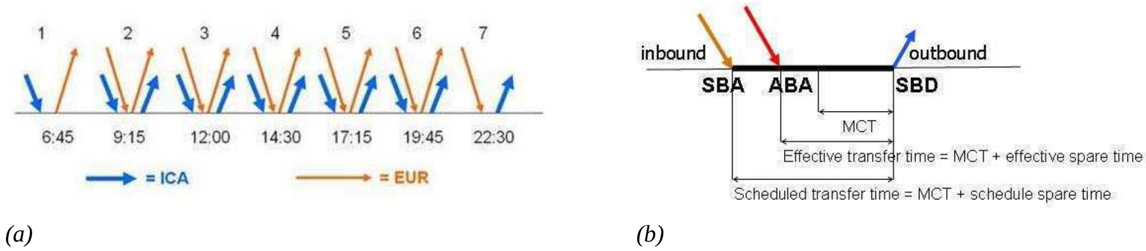

Figure 1. (a) Inbound and outbound KLM flights are organized at present in 7-banks system at Schiphol. Times shown are the local times (LT). Blue lines denote intercontinental flights (ICA) and the orange ones European flights (EUR) ; (b) Schematic representation of connecting flights: inbound flight is represented by the orange arrow (SBA-scheduled on-block arrival, i.e., the time a flight is scheduled to arrive at the gate, according to the timetable); delayed arrival is given by the red arrow (ABA-actual on-block arrival; i.e., the time the flight actually arrived at the gate); outbound flight is denoted by the blue arrow (SBD-scheduled off-block departure; i.e., the time a flight is scheduled to depart from the gate, according to the timetable). Scheduled transfer time is the time between the scheduled on-block arrival of the inbound flight and scheduled off-block departure of the outbound flight the passenger is transferring to (calculated as SBD-SBA). Scheduled transfer time consists of the MCT and the scheduled spare time. Effective transfer time is the time between actual arrival time (gate) of the inbound flight and the scheduled departure time (gate) of the outbound flight the passenger is transferring to (calculated as SBD-ABA). Effective transfer time consists of the MCT and effective spare time.

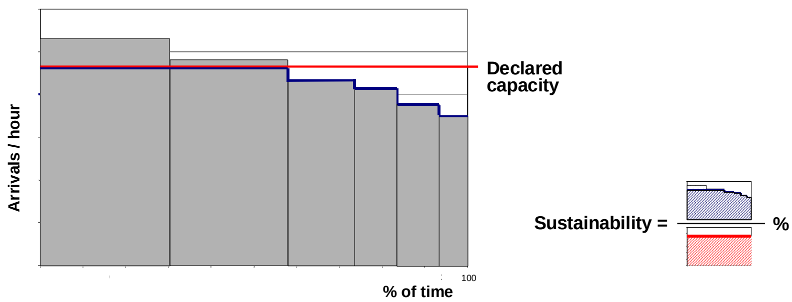

Figure 2. Determination of the sustainability of hourly capacity. On x-axis percentage of time for a certain available capacity forecast (given on y-axis) is presented. Sustainability is a ratio between the gray area under the red line and the whole area under the red line (declared capacity).

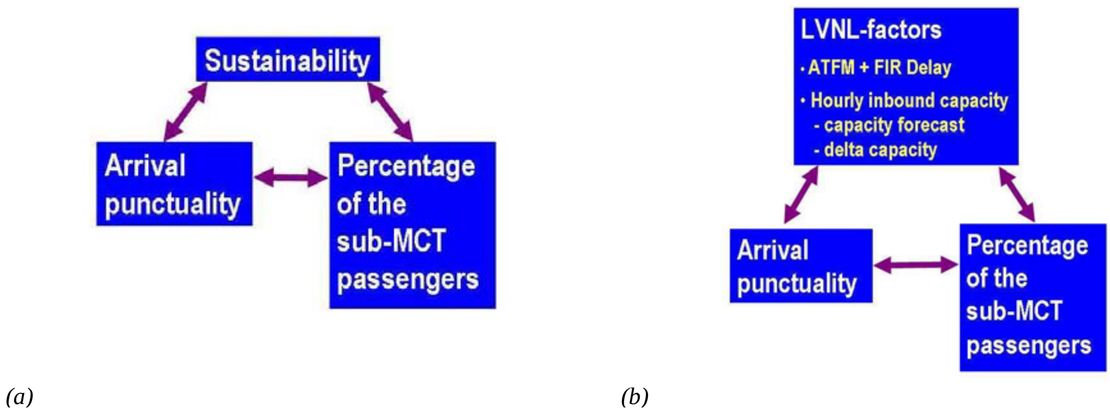

Figure 3. (a) Research framework at the higher aggregation level; (b) Research framework on the lower aggregation level.

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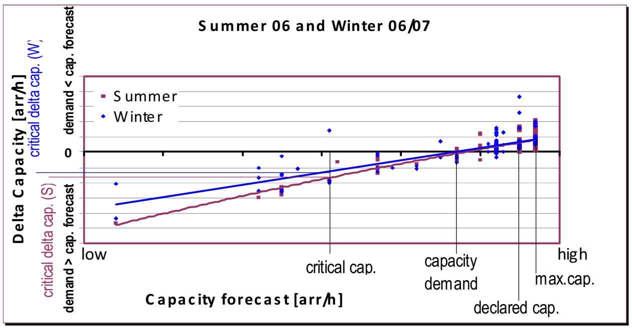
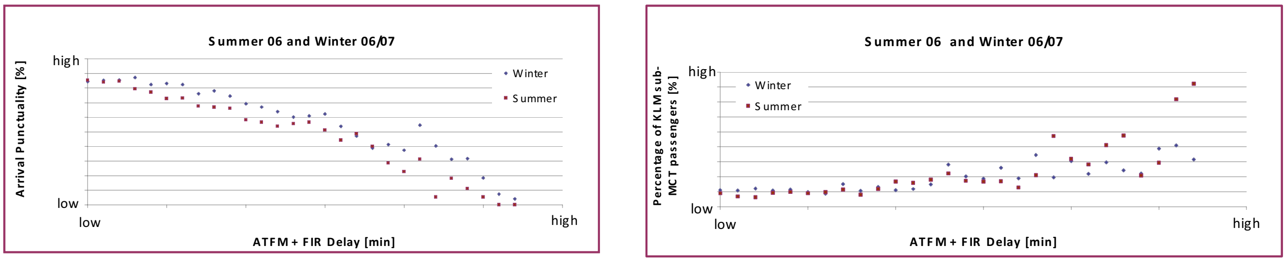


Figure 4. Delta capacity vs. LVNL capacity forecast.

(a) *(b)*

Figure 5. (a) ATFM+FIR Delay vs. LVNL capacity forecast; (b) ATFM+FIR Delay vs. delta capacity. Each point represents the ATFM+FIR Delay calculated as an average value for a given capacity forecast or delta capacity value.



(a) *(b)*

Figure 6. (a) Arrival punctuality vs. ATFM+FIR Delay; (b) Percentage of the KLM sub-MCT passengers vs.. ATFM+FIR Delay. Each point represents the arrival punctuality and percentage of the KLM sub-MCT passengers, respectively, calculated for each ATFM+FIR Delay.

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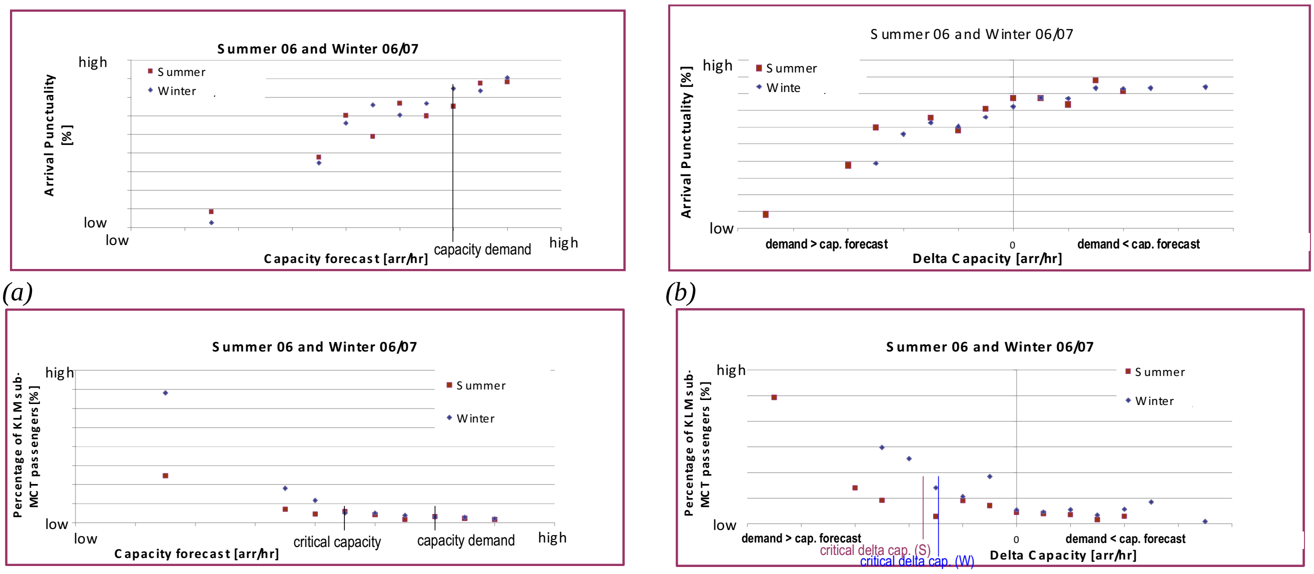

(a) *(b)*

(c) *(d)*

Figure 7. (a) Arrival punctuality vs. capacity forecast; (b) Arrival punctuality vs. delta capacity forecast; (c) Percentage of the KLM sub-MCT passengers vs. capacity forecast; (d) Percentage of the KLM sub-MCT passengers vs. delta capacity. Each point represents the arrival punctuality and percentage of the KLM sub-MCT passengers, calculated for each capacity forecast and delta capacity, respectively. These graphs are not fitted, because the number of measurement points in the region below critical (delta) capacity is not enough to obtain a reliable fit.

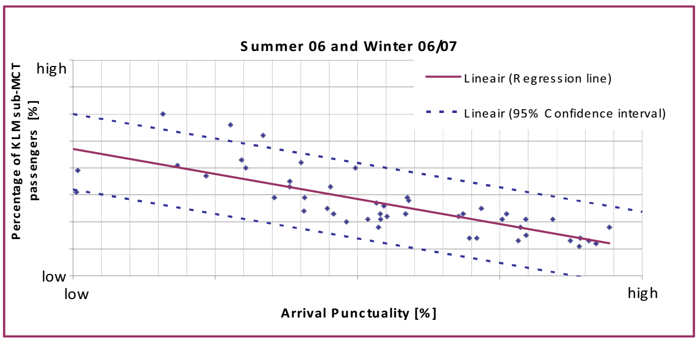

Figure 8. Percentage of the sub-MCT passengers vs. arrival punctuality. Each data point corresponds to the arrival punctuality and percentage of the sub-MCT passengers for a period of 30 days starting at the first day of the summer season (March 26th, 2006) and ending at the last day of the winter period in 2007 (March 24th, 2007). Use is made of sliding window with a window of 30 days and rolling with a timeframe of one week. Hence the first data point corresponds to the arrival punctuality and percentage of the sub-MCT passengers of the flights between the period of March 26th – April 24th. The second data point corresponds to the period from April 2nd – May 1st etc.

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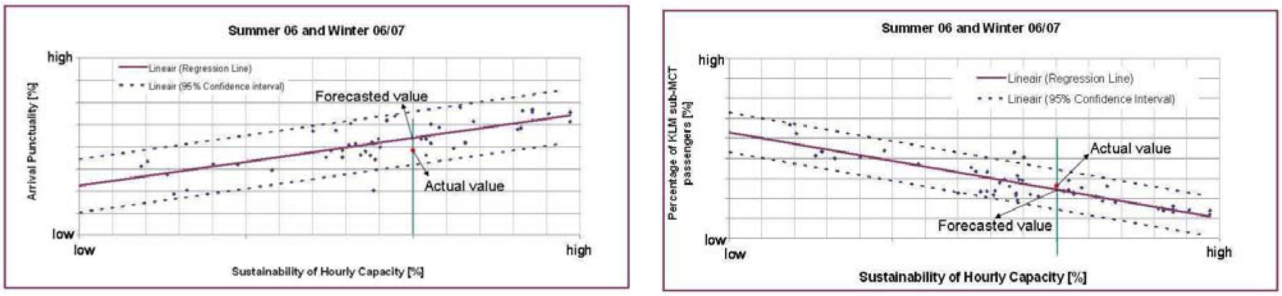

(a) *(b)*

Figure 9. (a) Arrival punctuality vs. sustainability of hourly capacity; (b) Percentage of the sub-MCT passengers vs. sustainability of hourly capacity. Each data point is calculated as in Fig. 8.

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