Methodological issues raised by DAA

Sizing of Dublin Airport Terminal 2

Report to the Commission for Aviation Regulation

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analysis for confidence in policy

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Contents

1 Introduction

Background

1.1 This report presents an analysis, and a consequent rebuttal, of criticism made by DAA of a methodology used in the preparation of my report 'High level analysis of DAA's investment plans' dated 9 February 2007 and of data supplied by me to Vector Management Limited (VML) which was used in VML's work reported in 'Review of Dublin Airport Authority Capital Expenditure Programme, Report No. 4 – Review of DAA Terminal Sizing' (RRV report 4) dated 16 May 2007. These reports were addressed to the Commission for Aviation Regulation (CAR) and informed its 'Draft Decision: Interim Review of 2005 Determination on Maximum Levels of Airport Charges at Dublin Airport' (CP5/2007) dated 21 May 2007.

1.2 The methodology relates to the measurement of busy hour passenger flow rates in an airport, the '95% busy hour', an important measure that is relevant to the assessment of the level of capacity that is required to maintain acceptable levels of service even when the airport is busy.

1.3 On page 51 of its response to CP5/2007, 'Response to Draft Decision' dated 21 June 2007, Dublin Airport Authority (DAA) described my methodology and the data arising from it as "mathematically incorrect" and a source of "serious methodological deficiencies". It concluded that "any conclusions drawn from this flawed data are unsound". It also suggested that "a previous IMR analysis had been so comprehensively challenged by DAA". DAA made similar comments on pages 4-5 of its June 2007 response to RRV report 4 and presented some more detailed comments on pages 15-16.

1.4 This report demonstrates the mathematical integrity of the methodology I have used and explains why the CAR can be reassured that that methodology is sound and equivalent to DAA's own except for the fact that it uses a richer set of data. This means it is less prone to potentially misleading arbitrary effects than DAA's and therefore more suitable for the purpose of discerning trends and making high-level comparisons, the purpose to which it was put. It is important to note that I have not argued and do not argue that the methodology and simpler data set that DAA uses is inappropriate for its purpose of informing the design of new airport facilities.

1.5 I also comment more generally on DAA's review of my previous analysis.

The busy hour measure

1.6 The source of DAA's criticism appears to be its conclusion that a rolling hour basis for calculating the '95% busy hour' for passenger flows is incorrect. On page 15 of its response to RRV report 4, DAA stated:

> However, the 95% Busy Hour for EI as supplied by the DAA is significantly different from the 95th Busy Hour used by VML, which we understand was supplied by IMR. VML suggests that the reason for this difference is that the DAA figures are based on clock hours, while IMR's figure is based on a rolling hour (rolling every 15 minutes). It is mathematically impossible for the rolling hour peak to be less than the clock hour peak since the rolling hour must at some point be coincident with the clock hour. Furthermore, when the DAA supplied its BHR data to VML, it alerted VML to this issue by stating "*please note that all calculations are based on clock hours, it is likely that a rolling hour would give* ***higher*** *values.*" Therefore, the DAA does not accept this lower IMR figure which we are unable to replicate.

1.7 In summary, DAA argument appeared to be that, as rolling hour peaks are bound to be no lower than clock hour peaks, a 95% busy hour calculated on a rolling hour basis is likely to be **higher** than a clock hour measure and because IMR's measure is **lower** it must be mathematically incorrect.

1.8 DAA is entirely accurate to note that it is mathematically impossible for the rolling hour peak to be less than the clock hour peak since the rolling hour must at some point be coincident with the clock hour. However its inference that that result will simply translate to a 95% busy hour calculation is mathematically wrong, which I demonstrate in this report. I demonstrate that DAA's suggestion that my methodologies are mathematically incorrect was unfounded and is mathematically untrue.

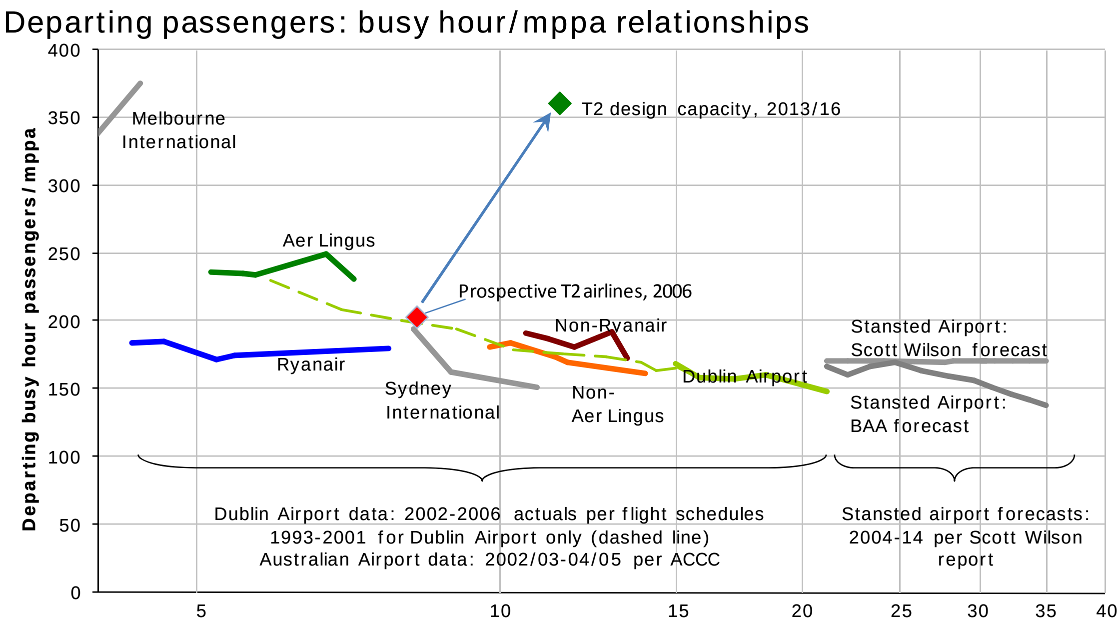
2 The context: the sizing of T2

Assumptions for T2 vs. historical trends

2.1 In its response to CP5/2007, DAA suggested that it "had identified serious methodological deficiencies in IMR's previous analyses and had documented these in a previous submission".

2.2 This previous submission was a paper entitled 'Review of High Level Analysis of DAA's investment plans by IMR', included with DAA's response to the CAR's CP1/2007. That paper addressed a number of issues raised in my report 'High Level analysis of DAA's Investment Plans' published with CP1/2007.

2.3 The central theme of my report was that the relationship between the busy hour capacity requirement for departing passengers at T2 calculated by DAA and the annual passenger flows DAA expects at the time when that capacity would be needed was very substantially out of line with the historical relationships over many years at Dublin airport and equivalent relationships at other airports where we had access to data. I characterised the problem in a chart, which I reproduce below together with one further point on the chart which I have calculated since.



Sources: DAA flight schedules, William Hynes & Associates
Scott Wilson December 2006 report to CAA, ACCC

2.4 The calculation of the additional point, the red point for prospective T2 airlines in 2006, uses a data set which I have reconciled (with DAA's assistance) to data used by DAA in its response to my earlier report[1]. The significance of the additional point is that it relates directly to the mix of airlines assumed by DAA in its analysis of capacity need in T2 (whereas, previously, I could only estimate that the point would be somewhere between the Aer Lingus line and the 'Non-Ryanair' line).

2.5 This data set shows that prospective T2 airlines handled some 8.3 million passengers in 2006. This means that DAA's expectation of about 11.5 million passengers in 2013 represents growth of some 39% (over six years, representing a healthy growth rate of 4.9% per annum). I calculate the busy hour passenger flow for 2006 for those airlines at 1,683 passengers, compared to a 2013 projection of 4,144, an apparent increase of some 146%, a full 100% greater than the growth in annual passengers. Using DAA's methodology, I calculate a slightly higher busy hour rate of 1,797, but that still leaves an increase of some 131% between 2006 and 2013. In either case, it represents a very marked apparent change in the relationship between busy hour and annual flows.

2.6 On the face of it, such a large change looks very significant and worthy of an explanation.

2.7 Logically, there could be four kinds of explanation:

- That T2 is designed to be able to handle more than 11.5 million passengers
- That T2 is designed to provide a high standard of service to more than just 95% of the 11.5 million passengers that are expected to use T2 by 2013 (i.e. departing from a conventional 95th percentile standard)
- That the operational patterns of prospective T2 airlines are expected to be very different in 2013 compared with 2006, leading to a higher requirement for busy hour capacity per million annual passengers
- That the busy hour measure identified for 2006 (using either a rolling or clock-hour basis) is inappropriate or inappropriately calculated and significantly understates the true busy hour passenger flows in that year.

2.8 My report sought to explore the possible explanations and invite DAA to provide a more detailed rationale for why the passenger flow profile for prospective T2 airlines might be so different. Had DAA been able to provide that, it would have been able to explain why a design capacity of

[1] DAA pointed out that my data set did not exclude a relatively small number of transfer passengers that we agreed should not have a material impact on the analysis.

4,200 passengers per hour had been used and why it was consistent with an annual throughput of only some 11.5 million passengers.

2.9 Instead, DAA claimed in its March 2007 response to my report that "the T2 airlines are not expected to change their profile significantly", suggesting that "the only difference is that the peak hour itself gets slightly 'peakier', which is natural considering the extra capacity developed". In that response, DAA did not suggest that my busy hour measures were in any way inappropriate. The logical inference was that the main explanation would lie somewhere in the first two bullets of paragraph 2.7, either of which might still have assisted DAA's case for the size of T2 if it could present and justify the rationale[2].

2.10 It was not until its 21 June 2007 response to CP5/2007 (and evidently in its preceding dialogue with VML) that DAA suggested that my busy hour measures are mathematically flawed. I address this latter challenge in full in section 3 below.

The profile of prospective T2 airlines

2.11 To support DAA's claim that "the T2 airlines are not expected to change their profile significantly", DAA set out, in its review of my report, an analysis of the departures for prospective T2 airlines for two relatively busy day in 2006 and for the period June to September 2006. It concluded from this analysis that the design day profile that it had used was "in fact similar to that in 2006 [and thus] it is a reasonable and proportionate representation of the operating patterns in the future".

2.12 With DAA's assistance, I have been able to recreate the data set used by DAA for this analysis and I set out below a table showing some key statistics.

[2] Subject to planning constraints, it might have been open to DAA to justify building for more annual capacity if it were more cost-effective to build a large box in one go rather than build smaller boxes and extending them. It would also be open to DAA to justify providing capacity for more than just 95% of passengers if the improvements in service levels for the 5% of passengers affected would be large enough to justify the additional costs.

Profile of prospective T2 airlines

Busy hour departing passengers

	Date	Rolling peak hour	Per-centile	Days with peaks as large	Pax in day	Peak/ day	Day/ year	ARR + DEP mppa	Peak/ mppa
2006									
95% Busy Hour for year	-	1,683	95.0%	199	-	-	-	8.3	203
Average day* in the year	-	1,718	95.7%	187	11,454	15.0%	0.27%	8.3	207
August bank holiday Friday	04 Aug	1,793	96.9%	154	13,701	13.1%	0.33%	8.3	216
95% Busy Hour for Jun-Sep	-	1,800	97.0%	150	-	-	-	8.3	217
Average day* in Jun-Sep	-	1,912	98.4%	89	12,945	14.8%	0.31%	8.3	231
DAA's typical busy day	23 Jun	2,121	99.5%	31	14,712	14.4%	0.35%	8.3	256
Busiest day of the year	30 Jun	2,345	99.9%	5	14,882	15.8%	0.36%	8.3	283
Peak hour of the year	01 Sep	2,582	100.0%	1	13,773	18.7%	0.33%	8.3	312
2013/16									
Design day for T2	-	4,144	-	-	23,885	17.3%	0.42%	11.5	360

** The rolling peak hours for the average days in the year and in Jun-Sep are calculated as the average of the rolling hour peaks calculated for each of those days. The corresponding average clock hour peaks are 1,613 for 2006 and 1,813 for Jun-Sep.*

2.13 A number of observations can be made. The first is that it is not unusual to have a peak hour bigger than a 95% busy hour. 199 days in 2006, 55% of the total, had a bigger rolling peak hour at some point in the day (159 days, or 44%, had a bigger clock hour peak). Nevertheless, it is only 5% of passengers that actually experience those peaks. There may be a case for using a higher percentile[3] as a guideline figure, but DAA has not formally suggested that it should do so.

2.14 The second observation is that the peak/mppa[4] statistic for the T2 design day is substantially bigger than it is for even the peakiest hour in 2006. It is this statistic that has driven my analysis, mainly because it is a conventional high-level statistic. If it looks high, it does not necessarily mean it is wrong, but it does point to some important questions that should be asked, and which were the subject of my February 2007 report.

[3] Since the peak measures in this table, and the busy day peak hour figure DAA used for the sizing of T2, are rolling hour peaks, it is appropriate to calculate percentile statistics with reference to the whole population of rolling hour flows during the year.

[4] ‘mppa’ means million passengers per annum.

2.15 The table above helps understand the key features of this apparent discrepancy. The two that stand out are:

- The design day for T2 is a 16% busier day, as a proportion of the year (assuming 11.5 mppa), than the busiest day in 2006.
- As a proportion of the day, the design day peak is almost as big as the peakiest day in 2006 (it is some 7% lower) and bigger than any other of the days in the table[5].

2.16 If DAA is correct in its assertion that the T2 airlines are not expected to change their profile significantly, then the design peak that DAA has chosen to guide its decisions about T2 looks large for the peakiest hour of the peakiest day of a year with 11.5 million passengers.

2.17 There may be more to DAA's explanation that airlines may well use the capacity if it is available, but this would represent a change in their profile and would not necessarily be a proper justification for building that capacity – using capacity when the marginal cost to the user of using that capacity is zero does not necessarily mean the incremental value of that capacity to the user is greater than the incremental cost of creating it.

2.18 Which leaves the fourth kind of explanation in paragraph 2.7 above: that the busy hour measures are inappropriately calculated. This is the subject of the next section.

5 DAA's claim that T2 airlines are not expected to change their profile significantly was based on its analysis of this proportion for the average day in Jun-Sep and for 23 June (although I calculate slightly different proportions than shown in DAA's graphs, the differences are not significant and DAA has confirmed that my calculations are correct). DAA extended the analysis to take into account scheduled departure times rather than actual departure times, suggesting that the scheduled peaks were higher and that scheduled peaks would be a better reference point for terminal design, which I do not necessarily accept. Scheduled departure times were not included in the data provided to the CAR, described in paragraph 0. DAA's calculated peak/day proportions using scheduled departure times are still smaller than the proportion for the T2 design day.

3 The measurement of busy hour passenger flows

The principles

3.1 In common with other airport operators, the time of all aircraft arrivals at and departures from Dublin airport is recorded by DAA, together with the number of passengers on board each aircraft, the airline name and other information. Times are recorded to the nearest minute when aircraft leave or arrive at a terminal gate and when aircraft take off from or land on a runway. In response to an information request, DAA provided the CAR with extracts from its flight schedules showing certain information for all aircraft movements for the years 2002 to 2006. For 2006, this amounted to 3.0 million cells of data for 186,001 records of aircraft movements, and similar volumes of data for earlier years.

3.2 These data can be analysed to provide important insights into the patterns of passenger flows through the airport's terminal facilities. Measuring when passengers take-off or land does not tell us exactly how many passengers will be using different facilities of the terminal at any one time, but it does provide a definitive base of information that can be used to assess the levels of capacity required in those facilities. The periods of high departure flow rates at the runway are liable to be preceded by periods of high flow rates through the departures facilities in the terminals. Periods of high arrival flow rates at the runway are liable to precede high flow rates through the arrivals facilities in the terminals. Capturing flow rate data at one part of the process provides data relevant to all parts.

3.3 Flow rate statistics are commonly used in the design of airport facilities, and the busy hour flow rate appears to be the benchmark measure. In common with some other airport operators, notably BAA in the UK, DAA uses a busy hour measure I will call the 95% Busy 00 Hour[6]. The 95% Busy 00 Hour identifies a flow rate, passengers per clock hour, at or below which at least 95% of passengers use the airport.

3.4 It is accepted by airport designers that it is not economic to design airport facilities to handle the absolute peak flow of passengers in a year, as the facilities would be under-utilised for all but one hour of the year. An airport facility designed for a 95% Busy Hour level of flow should provide levels of service to the desired standard for 95% of passengers. Some hours will inevitably be more congested and service levels might dip below

6 DAA has called this measure the 95% Busy Hour, but I insert the "00" to distinguish it as a measure using 'clock hours', hours defined as starting 00 minutes after the 'o'clock.

the standard for those periods, but only a small minority of passengers should be affected.

3.5 It is important to recognise that a busy hour flow measure only captures one dimension of information. By itself, it does not differentiate between long-haul and short-haul, domestic and business, adults and children and other characteristics that can affect how and when airport facilities are used. A busy hour flow rate of 4,200 passengers has however been presented by the DAA as a guideline measure of capacity for its new terminal when annual flows are expected to be around 11.5 million passengers and the analysis by myself and VML has sought to relate this prospective busy hour rate to historical busy hour flows.

3.6 Before attempting to measure these flows, one must first decide how to define an hour. Does an “hour” have to be a clock hour, one that starts at the o’clock and ends at 59 minutes past? Does it make a difference if the hours are defined differently, starting at 15 minutes past the hour for example? If it does, would a rolling hour measure that evens out those differences be a more suitable basis for comparative analysis?

3.7 The table after paragraph 3.30 below shows that the definition of the hour can make a big difference to the measure. For example, the busy hour calculation done on a clock hour basis, the 95% Busy 00 Hour, for 2003 for Aer Lingus departing passengers was 1,413 passengers, while exactly the same calculation done for hours starting at 30 minutes past the hour, the 95% Busy 30 Hour, was 1,135 passengers. One is 24.5% higher than the other, using precisely the same methodology but just different starting points for the hours used. Of the 16 sets of measures shown in that table, the average difference between the highest and lowest results, arising <u>only</u> because of the start-point of the hour, is about 10%.

3.8 The reason for these big differences relates to the characteristics of the flows. If the airlines being analysed happen to have schedules that tend to have hour-long peaks that broadly coincide with clock hours, the 95% Busy 00 Hour measure will give the biggest result. If they have hour-long peaks that broadly centre on o’clock times, the 95% Busy 30 Hour would give the biggest result while the 95% Busy 00 Hour would be liable to give the smallest result (because no one hour’s data in the calculation will contain more than a half-hour’s worth of a peak).

3.9 Given these issues, and reflecting the fact that DAA was itself measuring peak flows on a rolling hour basis[7], it seems natural to use a rolling

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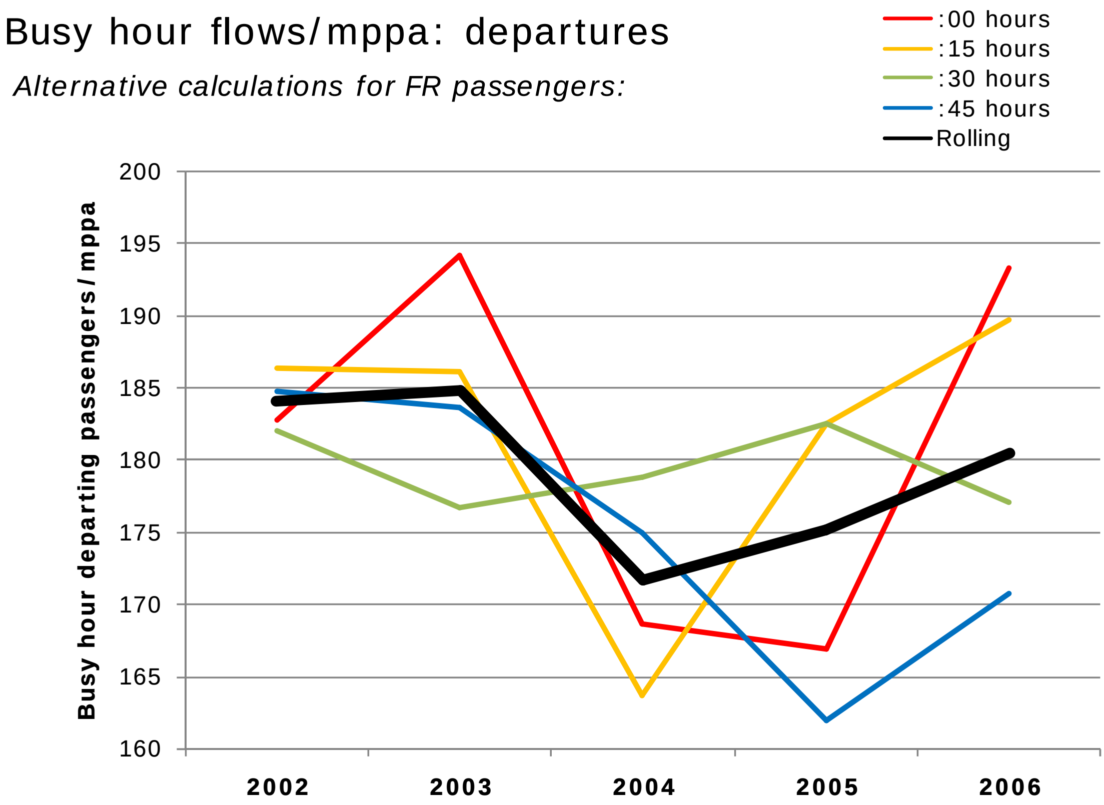
[7] The DAA’s calculation of 4,200 is based on a projection of flight schedules for a typical busy day in 2013 (stated as 2016 in its Gateway 2 document) for which the rolling hour peak is 4,144 passengers. The clock hour peak for that same projection is 2,699 passengers.

definition of an hour to smooth out these differences and give a measure of the busy hour flow that is less prone to arbitrary coincidences between hour definitions and airline schedules.

3.10 The effect of these arbitrary coincidences is graphically illustrated in the chart below, which shows the results of different hour definitions for Ryanair departures:



3.11 The graph shows that, with this data set, no one definition leads to a consistently higher or lower figure than any other and that, in some years, reliance on any one of the non-rolling definitions could give a misleading view of the underlying trend. The rolling basis of measuring the busy hour flow avoids this problem and provides a more balanced, less arbitrary result.

3.12 However, DAA has claimed that the rolling hour measure I used is "mathematically incorrect". I shall demonstrate the mathematical integrity of the rolling hour measure in the following section and demonstrate that DAA's claim is unfounded.

The mathematics

3.13 I shall start by defining some terms.

Clock hour definitions

3.14 First, I define the series of data forming the basis of the clock hour based busy hour measure (for any one year and any one category of passengers, e.g. all Dublin airport passengers or all departing Aer Lingus passengers):

- D_{00} is the series representing the number of passengers in each clock hour in the year, hours starting at 00 minutes past each hour
- D $= \sum(all\ D_{00})$, the total number of passengers in the year
- D_{00}^{95} is the '95% Busy 00 Hour', the lowest X such that $\sum(all\ D_{00} \leq X) \geq 0.95 \times D$ (this identifies a flow rate, passengers per clock hour, at or below which at least 95% of passengers used the airport)

3.15 It follows, fairly trivially, that if $Y < D_{00}^{95}$, then $\sum(all\ D_{00} \leq Y) < 0.95 \times D$.

3.16 It also follows, equally trivially, that if $Z \geq D_{00}^{95}$, then $\sum(all\ D_{00} \leq Z) \geq 0.95 \times D$.

Other hour definitions

3.17 We can then define equivalent terms for the series of data for hours starting at a different number of minutes past each hour, specifically 15, 30 and 45 minutes past each hour: D_{15} , D_{30} and D_{45}. Recognising that $\sum(all\ D_{00}) = \sum(all\ D_{15}) = \sum(all\ D_{30}) = \sum(all\ D_{45}) = D$ (there are not usually significant departures close to midnight on New Year's Eve to confuse things), we can also define equivalent terms for the 95% Busy 15 Hour, 95% Busy 30 Hour and 95% Busy 45 Hour: D_{15}^{95} , D_{30}^{95} and D_{45}^{95}.

3.18 Equivalent results to that in paragraph 3.15 above, but for D_{15} , D_{30} and D_{45}, can also be derived.

3.19 Similarly, equivalent results to that in paragraph 3.16 above, but for D_{15} , D_{30} and D_{45}, can also be derived.

Rolling hour definitions

3.20 Suitable rolling hour terms can then be defined:

- D_{roll} is a series of data made by combining the series D_{00} , D_{15} , D_{30} and D_{45} (in any order)

- D_{roll}^{95} is the rolling '95% Busy Hour', the lowest X such that $\sum(all\ D_{roll} \leq X) \geq 0.95 \times 4 \times D$ (this identifies a flow rate, passengers per hour, at or below which at least 95% of passengers used the airport)

3.21 It follows that an equivalent expression for D_{roll}^{95} is the lowest X such that $\left[\sum(all\ D_{00} \leq X) + \sum(all\ D_{15} \leq X) + \sum(all\ D_{30} \leq X) + \sum(all\ D_{45} \leq X)\right] \geq 0.95 \times 4 \times D$.

3.22 Another way of writing this expression for D_{roll}^{95} is that it is the lowest X such that:

$$\frac{\sum(all\ D_{00} \leq X) + \sum(all\ D_{15} \leq X) + \sum(all\ D_{30} \leq X) + \sum(all\ D_{45} \leq X)}{4} \geq 0.95 \times D$$

3.23 It also follows that if $Z < D_{roll}^{95}$, then $\sum(all\ D_{roll} \leq Z) < 0.95 \times 4 \times D$

3.23 It also follows that if $Z < D_{roll}^{95}$, then $\sum(all\ D_{roll} \leq Z) < 0.95 \times 4 \times D$

The minimum value for the rolling '95% Busy Hour'

3.24 I shall now demonstrate mathematically that the rolling 95% Busy Hour measure cannot be lower than the minimum of D_{00}^{95} , D_{15}^{95} , D_{30}^{95} and D_{45}^{95}. I shall do this using a conventional mathematical technique of showing that if the statement were false, a logical contradiction occurs, and hence the statement must be true (*reductio ad absurdum*).

3.25 If the statement were false, it would be possible for $D_{roll}^{95} < \min\ (D_{00}^{95}, D_{15}^{95}, D_{30}^{95}, D_{45}^{95})$. It would follow from the results in paragraphs 3.15 and 3.18 that $\left[\sum(all\ D_{00} \leq Y) + \sum(all\ D_{15} \leq Y) + \sum(all\ D_{30} \leq Y) + \sum(all\ D_{45} \leq Y)\right] < 0.95 \times 4 \times D$ where $Y = D_{roll}^{95}$. But this result directly contradicts the defining expression for D_{roll}^{95} in paragraph 3.21 above. This logical contradiction proves the statement must be true.

The maximum value for the rolling '95% Busy Hour'

3.26 I shall now demonstrate mathematically that the rolling 95% Busy Hour measure cannot be higher than the maximum of D_{00}^{95} , D_{15}^{95} , D_{30}^{95} and D_{45}^{95}, again by showing a logical contradiction occurs if it were false.

3.27 If the statement were false, it would be possible for $\max\ (D_{00}^{95}, D_{15}^{95}, D_{30}^{95}, D_{45}^{95}) < D_{roll}^{95}$. Paragraph 3.23 requires that $\left[\sum(all\ D_{00} \leq Z) + \sum(all\ D_{15} \leq Z) + \sum(all\ D_{30} \leq Z) + \sum(all\ D_{45} \leq Z)\right] < 0.95 \times 4 \times D$ where $Z = \max\ (D_{00}^{95}, D_{15}^{95}, D_{30}^{95}, D_{45}^{95})$. However, it also follows from paragraphs 3.16 and 3.19 above that $\left[\sum(all\ D_{00} \leq Z) + \sum(all\ D_{15} \leq Z) + \sum(all\ D_{30} \leq Z) + \sum(all\ D_{45} \leq Z)\right] \geq 0.95 \times 4 \times D$ (because each of the four terms inside the square brackets must be

$\geq 0.95 \times D$, so their sum must be $\geq 0.95 \times 4 \times D$), which is directly contradictory. This logical contradiction proves the statement must be true.

Mathematical symmetry

3.28 The rolling ‘95% Busy Hour’ measure is therefore bound to be somewhere between the maximum and the minimum of the non-rolling measures, and there is an apparent mathematical symmetry in these two results. The source of the mathematical symmetry can be seen in the structure of the expression in paragraph 3.22 and how it compares with the expression for the clock hour measure in 3.14 (and corresponding measures in 3.17).

3.29 It can be easily seen that, for any level of X, the difference between the sum on the left hand side of the expression in paragraph 3.22 and the 95th percentile expression on the right will be the same as the average of the equivalent figures for each of the four non-rolling measures. This means that, unless the function on the left hand side of the expression in paragraph 3.22 is markedly non-linear across the range between the highest and lowest non-rolling 95% busy hour, the rolling 95% busy hour measure is likely to be somewhere in the middle of the range and close to the average of the four non-rolling measures. The function is, in fact, a step function, but there are likely to be a lot of steps over even a small range for large data sets such as the ones we are considering (for prospective T2 airlines in 2006, there were 368 steps between the highest and lowest non-rolling 95% busy hours), so the function will be relatively smooth. Over a small range, any smooth function will tend to be linear, so it is most unlikely to be markedly non-linear.

3.30 This indicates that there is no mathematical reason to infer that the rolling busy hour measure is more likely to be higher (or more likely to be lower) than any one of the non-rolling measures. To demonstrate this with an example, the following table shows the results of 16 sets of 95% busy hour calculations, and of the 64 possible comparisons, the rolling hour measure gives higher values in 48.4% of them, very close to a balanced outcome. In addition, although these 64 comparisons showed individual differences of up to 13% between rolling and non-rolling measures, the biggest difference between a rolling measure and the average of the four corresponding non-rolling measures is only 1.25% and, taking all 64 comparisons together, the overall average difference between the rolling and non-rolling measures is a tiny 0.02%. It thus empirically demonstrates, for the data sets relevant to T2, that the rolling measure substantially eliminates the arbitrary effects of when the hour is defined and evidently introduces no new bias.

3.31 The rolling measure is simply a consolidation of the four non-rolling measures and will be a less granular, more stable measure than any one of them used in isolation, it uses exactly the same methodology but uses a richer data set and is structured to reduce the arbitrary effects of when the hour is defined[8].

95% busy hour departing passenger flows

Alternative hour definitions:

	2002	2003	2004	2005	2006
All Dublin airport passengers (DUB)					
Hours starting :00	2,555	2,518	2,749	2,999	3,079
Hours starting :15	2,550	2,501	2,699	2,901	3,124
Hours starting :30	2,475	2,498	2,662	2,924	3,216
Hours starting :45	2,530	2,541	2,706	3,011	3,173
Rolling hours every 15 minutes	2,523	2,517	2,702	2,954	3,144
Aer Lingus passengers (EI)					
Hours starting :00	1,287	1,413	1,421	1,855	1,801
Hours starting :15	1,266	1,280	1,270	1,569	1,570
Hours starting :30	1,180	1,135	1,235	1,527	1,576
Hours starting :45	1,183	1,354	1,437	1,774	1,698
Rolling hours every 15 minutes	1,226	1,307	1,344	1,681	1,659
Ryanair passengers (FR)					
Hours starting :00	789	903	883	911	1,500
Hours starting :15	805	866	857	996	1,472
Hours starting :30	786	822	936	996	1,374
Hours starting :45	798	854	916	884	1,325
Rolling hours every 15 minutes	795	860	899	956	1,400
Prospective T2 airlines					
Hours starting :00	-	-	-	-	1,797
Hours starting :15	-	-	-	-	1,604
Hours starting :30	-	-	-	-	1,611
Hours starting :45	-	-	-	-	1,706
Rolling hours every 15 minutes	-	-	-	-	1,683

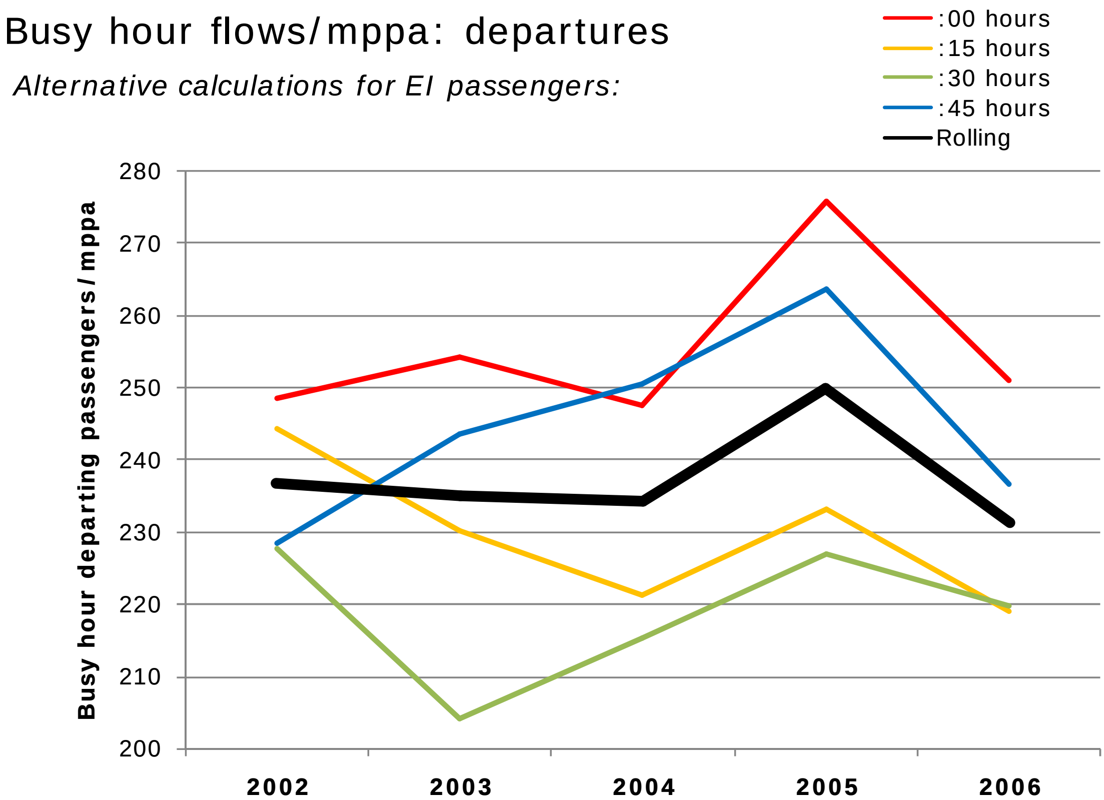
Conclusion from mathematical analysis

3.32 There is therefore no mathematical or empirical foundation for DAA's claim that "it is likely that a rolling hour would give **higher** values [than a clock-hour measure of the busy hour]" (DAA's emphasis), thus no foundation for its stated reason for rejecting my results and certainly no foundation for its claim that my analysis is mathematically incorrect.

[8] It will not completely eliminate such effects since there would be even smaller effects if we were to use, say, 5-minute rolling hours or 1-minute rolling hours.

Observation on the results for Aer Lingus

3.33 Although this mathematical analysis demonstrates the integrity of the rolling hour measure, it remains the case that the clock-hour measure for Aer Lingus appears to be consistently higher than the rolling hour measure. Because Aer Lingus is the dominant member of prospective T2 airlines, the clock-hour measure for those airlines is liable also be systematically higher (although, based on the 2006 figures, to a slightly lesser degree). The following chart illustrates the point – the red line is consistently higher than the thick black line.



3.34 As I discuss in paragraph 3.8, this would be a function of a coincidence between the timing of the peaks in Aer Lingus's schedules and the clock hours, a coincidence which appears to have been sustained over a number of years. In 2006, for Aer Lingus (and also for the prospective T2 airlines), 42% of the rolling hour peaks were clock hours, where one would normally expect only 25% of them to be.

3.35 In an objective sense, such a coincidence is arbitrary and introduces a bias in the measurement of the clock-hour-based busy hour measure. The apparent consistency in that bias for Aer Lingus does not exist in the equivalent measure for Ryanair (see the graph after paragraph 3.10).

3.36 While there is no obvious objective basis to prefer a clock-hour measure (the 95% Busy 00 Hour) to any other non-rolling measure, this arbitrariness could be addressed another way by measuring the busy hour flow rate as the maximum of the four non-rolling measures. This would introduce a new systematic upward bias in the measure and would represent a substantive change in methodology, but it would at least provide a more consistent and thus a more satisfactory measure than a single whole-hour measure. The rolling hour approach, however, achieves the objective of consistency without requiring a substantive change in the methodology.

4 Interpretation and conclusion

4.1 As I emphasised in my February 2007 report, I do not and cannot conclude from my analysis that T2 is too big. However, the analysis I have been able to carry out since that report reinforces my conclusion that, against a 95th percentile benchmark or any other plausible benchmark, T2 looks like it should be able to handle substantially more than 11.5 million passengers in a year.

4.2 I based my analysis in my February 2007 report on a 95% busy hour measure because it is a conventional measure relevant to the design of airport infrastructure. I used a rolling hour version of the measure because DAA used a rolling hour peak for its assessment of capacity and it is consistent to calculate percentile statistics with reference to the whole population of rolling hour flows during the year. However, my analysis would not have reached different conclusions had I used DAA's preferred clock-hour version. My February 2007 report highlighted an apparent discrepancy between historical values of the measure and the design capacity of T2 and raised a number of questions I considered relevant to the CAR's interim review of airport charges. Those questions remain valid.

4.3 My analysis in section 3 identifies that the measure used by DAA is significantly affected by the choice of when the hours should start. This is an unsatisfactory characteristic of the measure, and I have demonstrated that a rolling calculation largely solves that problem. However, acknowledging a point made by DAA, the analysis also highlights that a 95% busy hour measure should not be taken as the last word in terminal design – it is better at prompting the right sort of questions than at giving the answers.

4.4 For example, the 95% busy hour for prospective T2 airlines in 2006 was fairly frequently exceeded, at least for one short period in most days in the year. It appears to be DAA's view that there is an appetite among users of the airport for less frequent periods of congestion, even though they may only affect a small minority of passengers and not necessarily be very severe. If the value to users of avoiding congestion at these times is large enough, DAA should be able to justify using a higher benchmark than the 95th percentile.

4.5 But how much higher? The following table sets out the peak levels in departing passengers for prospective T2 airlines that were reached only for one in every 2, 4, 7, 10, 20 and 365 days during 2006. The table presents the corresponding percentile level, the simply extrapolated annual capacity for a terminal capable of handling 4,200 departing passengers per hour and a corresponding estimate of capacity that takes into account the effect of growth on the peak/mppa ratio. This effect, which would normally be a fairly natural consequence of more diversity of flights, is evident in the graph after paragraph 2.3.

Frequency of peaks: prospective T2 airlines, 2006

Busy hour departing passengers

Rolling peak reached only for one in every:	Rolling hour peak	Per-centile	Extrapolated annual capacity for 4,200 departures/hr†	Capacity estimate adjusted for growth*
2 days	1,730	95.9%	20.1 mppa	27.2 mppa
4 days	1,908	98.3%	18.2 mppa	23.8 mppa
7 days	2,019	99.1%	17.2 mppa	22.0 mppa
10 days	2,089	99.4%	16.7 mppa	21.0 mppa
20 days	2,182	99.7%	16.0 mppa	19.8 mppa
365 days	2,582	100.0%	13.5 mppa	15.7 mppa
95% busy hour	1,683	95.0%	20.7 mppa	28.3 mppa

† extrapolated from a 2006 base of 8.3 mppa
* capacity adjusted to take account of the effect of growth on peak/mppa ratios evident in the historical profile for Dublin airport, using a simple logarithmic trend

4.6 This table shows a range for the extrapolated annual capacity for T2 of between 13.5 and 28 mppa, although the figure of 13.5 mppa reflects the absolute most extreme of the 23,542 non-zero rolling hours of departing passengers in 2006. If one considers percentile benchmarks beyond 99% to be rather severe, considers the effect of growth is likely to be material and acknowledges DAA’s view that there may be a slight increase in peakiness, this analysis suggests that the realistic capacity of T2 might be between about 19 and 25 mppa. This capacity would be consistent with the very substantial majority of users of T2 experiencing no worse that the design standards of service.

4.7 This analysis remains top-down, based on high-level ratios, and is not a substitute for more detailed analysis. However, it does indicate that the serious questions raised by the CAR in February 2007 about the sizing of T2 remain largely unanswered: rather than answering those questions, DAA seems to have focused its efforts on challenging the validity of the analysis that led to them. This report shows important aspects of that challenge to have been mathematically and empirically unfounded.