Computing Model of Airspace Utilization Rate Based on Airspace Load

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Abstract—A model for the computation of the airspace utilization rate is put forward to help the airspace manager assess the airspace usage effectively. Through proposing the concept of “airspace load”, the airspace resource is quantified and a new definition of the airspace utilization rate is introduced. Based on the new definition and the research about airspace capacity and air traffic flow management, a model is established by analyzing the flying process of an en-route to compute the utilization rate of the en-route. To know the computation feasibility and ability of the model, it is applied to a given en-route in the computational results, the examples of which show that the model can simulate the operation process of the en-route and can reflect its usage situation.

Index Terms—Airspace Utilization Rate; En-Route Utilization Rate; Airspace Load; Airspace Capacity; Flight Time

I. INTRODUCTION

As the development of civil aviation transportation, a growing number of airspace is demanded by an increasing air traffic flow. Many flights are often delayed as the air traffic flow demanding exceeds the airspace capacity. It is possible to increase the air traffic flow and to reduce the number of delays by making the best use of airspace. The utilization rate of airspace is an important criterion to evaluate the airspace usage. It can help the managers improve the management of airspace by accurately calculating the utilization rate of airspace, so that the value of airspace will be used in maximum.

The research on airspace utilization rate is still underway. Min Xue analyzed the airspace tube utilization rate by “time-space” diagram, which is usually used to analyze the road traffic condition [1]. However, the author has just introduced this idea, while the detailed computing method has not been given.

Kapil S. Sheth analyzed the airspace tube utilization rate by computing instantaneous occupancy rate and volume occupancy rate [2]. The instantaneous occupancy presents how many aircraft are flying in the tube compared to the total number of aircraft at the same instant in time. This metric represents the temporal utilization of tubes. The volume utilization is defined in terms of the total number of aircraft that can possibly occupy each tube. This metric represents the spatial or volumetric utilization of tubes. However, these two definitions just take one dimension into consideration and they can’t reflect the real airspace usage accurately.

Shi Heping introduced the definition of basic airspace utilization rate and actual airspace utilization rate while the computing method was not given [3]. The basic airspace utilization rate can be defined as the ratio of the airspace that can be used to the space that can be flying in. The actual airspace utilization rate can be defined as the ratio of the airspace that has been used to the airspace that can be used.

Zhang Huili introduced the effective airspace utilization rate of flexible use of airspace based on the indexes of EUROCONTROL, including the time that the airspace can be used, the number of the aircrafts in the airspace and so on [4].

Zhang Bo put forward another definition of the airspace utilization rate, built evaluation indexes, considering the management and use of airspace, and computed the airspace utilization rate in gray correlation degree method. In addition, airspace utilization rate can be defined from the dimension of the flight time, the space or capacity of airspace [5].

Wang Ping put forward a new computing method of airspace utilization rate in principal component analysis and gray correlation degree method, considering the correlation among evaluation indexes [6].

Reference [5] and reference [6] have presented good evaluating methods of a whole airspace, while when it comes to compute the utilization rate of a detailed airspace during a period from a microcosmic aspect these two methods become invalid.

Because principal component analysis [7-10] and gray correlation degree [11] method are two methods that are adaptable to evaluate objects from the macroscopic aspect. There are also some other papers which are about optimizing of airspace capacity to ensure the best use of airspace [12-14].

However, all the studies mentioned above do not make full use of the data resulted from the actual use of airspace and the data resource is wasted. If we can find a simple method and use these data properly to compute the airspace utilization rate, it will be a practical mean to assess the airspace usage and will benefit for the airspace management.

In order to token the airspace utilization rate, firstly, the concept of “airspace load” is proposed according to the characters of the airspace. Then a new definition and
The available airspace load refers to the maximum ability of the airspace and it can’t be exceeded in practice, otherwise it will bring serious consequences including flight delays. The actual airspace load refers to the service ability that has been provided for aircrafts in practice. A well-run airspace system should show that the actual airspace load is infinitely closed to the available airspace load, but the actual airspace load should not exceed the available airspace load. In this range, the airspace load should be as great as possible, which is different from the work load of the person. The greater the available airspace load, the more services the airspace can provide and the more available flight flow. The greater the actual airspace load is, the more actual flight flow.

Therefore, the two indicators are used to measure the degree of efficiency of the airspace in this paper. The closer the space between the actual airspace load and the available airspace load is, the greater the airspace utilization rate.

There are so many factors that influence the operation of the airspace, such as the behavior of the aircrafts, the climate, the ability of the pilot and the air traffic manager, so we need a scientific and fast method to compute the airspace utilization in practice in order to reflect the usage situation of the airspace. We can also measure the airspace load from the three dimensions, including the time, the space and the capacity of the airspace. In the process of the operation of the airspace, it is using the time, the space and the capacity of the airspace to provide the flying service for the aircrafts.

Thus, the airspace load isn’t one dimension, while it is multi-dimensions. For different airspace systems, we should determine its airspace load from multi-dimensions according to its special structure and operation features in order to compute its utilization rate more accurately. If we measure the airspace load just from one dimension, there will be some deviation on the computing results, or even the computing results may be not conform to the actual situation.

Based on the analysis above, the airspace utilization rate can be redefined as follows:

In the given time period, the ratio of the actual airspace load to the available airspace load is called the airspace utilization rate. The computing formula is shown as follows:

\[ U = \frac{A'}{A} \times 100\% \]  

where:

- \( U \) : The utilization rate of the given airspace;
- \( A' \) : The available airspace load. It reflects the available work ability of the airspace in the given time period and it is usually decided by the maximum capacity of the airspace. It refers to the work ability of the airspace when the airspace is operated and the maximum capacity is reached. It includes both the ability that have been offered to flights and the potential capability that the airspace possesses but has not offered to flights;
- \( A \) : The actual airspace load. It means the airspace is released after an aircraft departs and it can also provide services for other aircrafts during the available time of the airspace, it must be used instantly. If the airspace has not been used at some time, the airspace has not created any value and the value of the airspace during that time can’t be used anymore. However, the total quantity of the airspace is hard to be determined.
$A_S$: The actual airspace load. It means the real ability that the airspace has provided for the actual flight and reflects the quantity of the airspace that has been used by the aircrafts.

Thus, the airspace utilization rate can be computed quantificationally. In order to ensure the practical meaning of the definition, the airspace utilization rate $U$ should meet with the mathematical qualification shown as follows:

$$0 \leq U \leq 1, \ U \in R.$$

### III. COMPUTING MODEL OF THE EN-ROUTE UTILIZATION RATE

The new definition of airspace load and airspace utilization rate and formula (1) will be applied to the en-route and calculation model of en-route utilization rate will be established in this chapter.

For a given en-route, the available airspace load is decided by route capacity, which includes the fixed capacity and the passing point capacity. The fixed capacity is decided by the length of the route, which means the space of airspace. Therefore, the available airspace load of the en-route can be confirmed by considering its space and capacity simultaneously. This available airspace load, decided by all three dimensions effectively, is the maximum ability that the en-route can afford.

Thus, the airspace load of an en-route is measured form the time dimension, considering the limits of the space and the capacity of the en-route. The definition of the en-route utilization rate is the ratio of the sum of the flying time of all aircrafts in the given time period to the sum of the flying time of all aircrafts that can be served in the given time determined by the en-route capacity and the length of the en-route.

#### A. Assumptions and Symbol Description of the Model

For conveniences of describing problems, the basic assumptions of the model are shown as follows:

In the given time period, the route capacity is not influenced by inclement weather and other stochastic factors, so the capacity in this paper is the static capacity of the airspace.

The air traffic is controlled by radar and the factors, such as the orientation precision of the navigation equipments, the delay of the communication and the control ability of the controllers, are not considered in the paper. Therefore, the margin of the flight separation is not needed.

Each type of aircrafts fly on the primary flight level at a constant speed.

The length of the fuselage is negligible.

Symbols of the model are described as follows:

$L$ — The length of the en-route;

$m$ — The total number of flight levels of the en-route;

$n$ — The number of the aircraft types;

$n_i$ — In the given time period, the actual air traffic flow of flight level $i$;

$S_j$ — The minimum safety separation between the aircrafts of type $j$;

$V_j$ — The flying speed on the primary flight level of aircraft type $j$;

$C_i$ — The passing point capacity of the entry of flight level $i$;

$C_{0i}$ — The fixed capacity of flight level $i$;

where, $i = 1, 2, \cdots m, j = 1, 2, \cdots n$.

#### B. Utilization Rate of the Flight Level

Aircrafts should fly according to the assigned flight levels during the stage of cruising. Therefore, the utilization rate of the flight level should be computed first in order to get the en-route utilization rate.

Based on the assumptions and symbol descriptions mentioned above, the flight level utilization rate is computed.

1) The Capacity of the Flight Level

Supposes that flight level $i$ is the primary flight level of aircraft type $j$, which flies at the speed of $V_j$.

According to the en-route capacity model based on the average flying speed [15-18], the passing point capacity of flight level $i$ can be obtained as follows:

$$C_i = \frac{1}{S_j / V_j} = \frac{V_j}{S_j}$$  \hspace{1cm} (2)

where, $C_i$ is the passing point capacity. It represents the number of flights that can be cleared into the flight level $i$ in an hour.

In fact, before the hour, which is the time period that is given to compute the passing point capacity, there are some flights which have already been flying on the level. In this time period, these flights can also be served. The number of these flights is called the fixed capacity of the flight level [19, 20], denoted as $C_{0i}$. Because the aircrafts of type $j$ on the flight level $i$ fly at a constant speed, so the fixed capacity is decided by the length of the en-route and the minimum safety separation between aircrafts of type $j$ and it can be computed as follows:

$$C_{0i} = \frac{L}{S_j}$$  \hspace{1cm} (3)

In addition, due to the constant speed of aircrafts, the minimum safety separation can be translated to the corresponding minimum safety time separation, the formula is shown as follows:

$$T_j = \frac{S_j}{V_j}$$  \hspace{1cm} (4)

2) The Available Airspace Load

The available airspace load, which is decided by the capacity of the flight level, is the maximum ability that can be offered by the flight level. It includes both the ability that has been offered to aircrafts and the potential ability that the airspace possesses but has not offered.
This maximum ability can be achieved only on condition that the flights are cleared and kept the minimum safety separation. Therefore, the available airspace load is computed on the same condition.

Supposes that the given time period is also an hour. In this period, the flights served by flight level $i$ include both the newly coming flights in this period and the flights that have already been flying on flight level $i$ at the beginning of this period. The available airspace load will be discussed and computed according to different relationships between the length $L$ of the en-route and the speed $V_j$ of the aircrafts flying on flight level $i$.

a) If $L \geq V_j$, the flying situation of flight level $i$ is shown in Fig. 1.

If $L \geq V_j$, then $C_{0i}$ will be no smaller than $C_i$, i.e. $C_{0i} \geq C_i$.

Therefore, at the end of the given period, the flights on flight level $i$ include the newly coming flights in this hour and the flights that have already flying on flight level $i$ at the beginning of this period while not having flown out at the end of the period. The flights that can be served by flight level $i$ in this period can be divided into three parts: the newly coming flights, the flights that have already been flying on flight level $i$ at the beginning of this period and the flights that have already been flying on flight level $i$ at the beginning of this period and have already flown out.

Therefore, in this case the available airspace load is computed as follows:

$$A_i = A_1 + A_2 + A_3$$

$$= [T_i + 2T_j + \cdots + (C_i - 1)T_j] + (C_{0i} - C_i + 1)CT_j$$

$$\quad + [T_i + 2T_j + \cdots + C_i T_j]$$

$$= C_{0i}C_i T_j$$

where:

$A_1$: The sum of the time that the flight level $i$ can serve in an hour for the newly coming flights;

$A_2$: The sum of the time that the flight level $i$ can serve in an hour for the flights that have already been flying on flight level $i$ at the beginning of this period while not having flown out at the end of the period;

$A_3$: The sum of the time that the flight level $i$ can serve in an hour for the flights that have already been flying on flight level $i$ at the beginning of this period and have already flown out.

b) If $L < V_j$, the flying situation of flight level $i$ is shown in Fig. 2.

If $L < V_j$, then $C_{0i}$ will be smaller than $C_i$, i.e. $C_{0i} < C_i$.

Therefore, after the given period, the flights on flight level $i$ include only the newly coming flights, while the flights that have already been flying on flight level $i$ at the beginning of this period have already flown out. The flights that can be served by flight level $i$ in this period can also be divided into three parts: the flights that newly come into the flight level and have not flown out, the flights that newly come into the flight level but have already flown out and the flights that have already been flying on flight level $i$ at the beginning of this period and have already flown out.

When computing the sum of flight time that can be used, we can unite the first kind and the third kind of flights and the sum of flight time that can be used for these flights can be obtained directly by formula (4). The flights that the passing point capacity exceeds the fixed capacity fly through the entire flight level in the period and spend the same time, which is the time an aircraft takes to fly through the entire en-route.

Therefore, in this case the available airspace load is computed as follows:

$$A_i = A_1 + A_2$$

$$\quad = C_{0i}C_i T_j + (C_i - C_{0i})C_{0i} T_j$$

$$\quad = C_i C_{0i} T_j$$

(6)

where:

$A_1$: The sum of the time that the flight level $i$ can serve in an hour for the flights that newly come into the flight level and have not flown out.

$A_2$: The sum of the time that the flight level $i$ served in an hour for the flights that the passing point capacity exceeds the fixed capacity.

$A_3$: The sum of the time that the flight level $i$ can serve in an hour for the flights that have already been flying on flight level $i$ at the beginning of this period and have already flown out.

According to the analysis above, the formulas of the available airspace load on the two conditions are the same. Both of them are decided by the length of the en-route.
and the minimum safety separation of aircraft type \( j \) on flight level \( i \). The available airspace load is proportional to the length of the en-route and inversely proportional to the minimum safety separation of aircraft type \( j \), which is accordant to the practical situation.

Because the aircrafts are assumed to fly on their principle flight level, the flight level \( i \) and the aircraft type \( j \) is corresponding. Thus, according to the formula (5) and (6), the airspace load can be denoted as follows:

\[
A_i = C_i C_{oT_i} T_i
\]  

(7)

3) The Actual Airspace Load

In practice, the air traffic controllers will not control the flying of the aircrafts according to the minimum safety separation strictly, but they will increase the separation technically. The reason for this is that the speed of the aircraft is actually a random variables, it would be influenced by a lot of random factors. This may result in that the available airspace load will not be fully used.

In order to compute the actual airspace load of the flight level in the given time period, the flight flow and the flying time of each aircraft should be computed. The computing of the air traffic flow is an important part of the air traffic management.

If the entering time of an aircraft is in the given time period, the aircraft should be counted as one flight served in this period. Based on the new definition of the airspace utilization rate, a new method of computing the air traffic flow is proposed in this paper. As long as the aircraft has appeared in the airspace in the given time period, the aircraft is one of the flights which is served by the airspace in this time period.

Supposed that \( T = [T_1, T_2] \) is the given time period, and \( [T'_1, T'_2] \) is the time period that the aircraft flying in the airspace, which can be obtained according to position information of the flight in the flight data recorder. So there are five relationships between \( T = [T_1, T_2] \) and \( [T'_1, T'_2] \), which are shown in Fig. 3.

In these five situations, the time of the aircraft flying out of the airspace is earlier than the starting time of the given time period in Fig. 3(a), and the time of the aircraft entering into the airspace is later than the ending time of the given time period in Fig. 3(e). Thus, these aircrafts in these two situations should not be included in the air traffic flow during this time period.

In Fig. 3(b), Fig. 3(c) and Fig. 3(d), some time period is overlapped during the two time period, so these aircrafts should be included in the air traffic flow.

“The aircraft has appeared in the airspace in the given time period” has three instances, which is shown in Fig. 3(b), Fig. 3(c) and Fig. 3(d). According to the relationships, the actual flying time in the airspace of each aircraft can be computed.

In Fig. 3(b), the aircraft is flying in the en-route at the beginning of the given time period and has already flew out the en-route at the end of the given time. In this situation, the time that the aircraft enters into the en-route is equal to the beginning of the given time period. Thus, the actual time that the aircraft flies in the en-route can be described as \( t = T_2 - T_1 \).

In Fig. 3(c), the aircraft flies into the en-route after the beginning of the given time period and has already flew out the en-route at the end of the given time. In this situation, the actual time that the aircraft flies in the en-route can be described as \( t = T_2 - T_1 \).

In Fig. 3(d), the aircraft flies into the en-route after the beginning of the given time period and has not flew out the en-route at the end of the given time. In this situation, the time that the aircraft flies out the en-route is equal to the end of the given time period. Thus, the actual time that the aircraft flies in the en-route can be described as \( t = T_2 - T_1 \).

The flying time of the aircraft in the airspace is the airspace load that the airspace has taken in order to serve the flying of the aircraft. In the given time period, the sum of the flying time of all aircrafts is the actual airspace load. Suppose that in one hour, the air traffic flow is \( n_i \), the flying time of each flight is \( T_{ik} \) \( (k = 1, 2, \ldots, n_i) \), which can be obtained with the method analyzed above. Finally, the actual airspace load can be computed as follows:

\[
A_a = \sum_{k=1}^{n_i} T_{ik}
\]  

(8)

4) Utilization Rate of Flight Level

After the available airspace load and the sum of the actual available airspace load is determined, according to formula (1), the utilization rate of flight level \( i \) can be computed as follows:

\[
U_i = \frac{A_a}{A_i} \times 100\% = \frac{\sum_{k=1}^{n_i} T_{ik}}{C_i C_{oT_i}} \times 100\%
\]  

(9)
C. Utilization Rate of the En-route

The flying situation of all flight levels in the en-route is shown in Fig. 4.

Because all aircrafts fly on its primary flight level and the minimum safety separation of different aircraft types are different, so the air traffic flow is distributed unevenly among the flight levels. Therefore, in order to get the precise results, the probability of each aircraft type in the en-route should be got from the history data. Based on the total number of the flights in the en-route and the total number of the flights on each flight level, the probability \( P_i (i = 1, 2, \ldots, m) \) of each aircraft type can be obtained.

Sum up the utilization rate of all flight levels weighted by the probability of each aircraft type in the en-route, the utilization rate of the en-route in a given hour can be computed as follows:

\[
U = \sum_{i=1}^{m} P(U_i) = \sum_{i=1}^{m} P_i \frac{\sum t_i}{C_i T_i} \times 100\% \quad (10)
\]

Table I. The related data information of each flight level

<table>
<thead>
<tr>
<th>FL.</th>
<th>( P_i )</th>
<th>Minimum safety separation</th>
<th>Actual Number of Flights</th>
<th>Sum of the Actual Flight time</th>
<th>Utilization Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>10 km</td>
<td>20</td>
<td>30 hours</td>
<td>76.92%</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>12 km</td>
<td>27</td>
<td>24 hours</td>
<td>73.85%</td>
</tr>
<tr>
<td>3</td>
<td>0.21</td>
<td>15 km</td>
<td>23</td>
<td>17 hours</td>
<td>65.38%</td>
</tr>
<tr>
<td>4</td>
<td>0.17</td>
<td>17 km</td>
<td>18</td>
<td>20 hours</td>
<td>87.18%</td>
</tr>
<tr>
<td>5</td>
<td>0.19</td>
<td>20 km</td>
<td>20</td>
<td>18 hours</td>
<td>92.30%</td>
</tr>
</tbody>
</table>

Thus, this paper will just take an en-route, 390 kilometers in length, as an example to verify this method. There are three flight levels in this en-route and the goal is to obtain the airspace utilization rate during a given time period 8:00-9:00. All three flight levels in the en-route are usable during this time period. There are mainly three aircraft types in the en-route and they fly on their primary flight level. Based on the history flight data, the probability of each aircraft type in the en-route can be obtained. During the time period, for each flight level, the time that each flight enters into the flight level and the time that each flight flies out of the flight level can be got according to the position information of the flight in the flight data recorder. The probability of each aircraft type in the en-route, Minimum safety separation, and other related data information is shown in Table I.

According to the time that each flight enters into the flight level and the time that each flight flies out of the flight level and based on formula (8), the actual airspace load of each flight level is obtained. The utilization rate of each flight level can be obtained according to formula (9) and finally according to formula (10) we can compute the utilization rate of the en-route at 78.40%.

This computing method can be applied to other en-routes. The parameters in this model are easy to be collected and computed. According to formula (9) and the utilization rate of each flight level, it shows that the computing result is mainly related to the speed and the flight flow and this can reflect the differences of different speed and different time period.

IV. COMPUTATIONAL EXAMPLE

This paper introduces a new definition of airspace load and a common computing formula of the airspace utilization rate, and applies them to build the calculation model of the en-route utilization rate.

On condition that the en-route capacity is not influenced by the inclement weather and other stochastic factors, the calculation model of the en-route utilization rate is obtained, which considers the flight time, the space and capacity at the same time. The data of each parameter in this model are all easy to collect and compute. And the computing results can reflect the differences of different en-routes and time periods.

In sum, this model can benefit to the airspace management and can be the theory basis of the future research on airspace utilization rate.

V. CONCLUSION

This paper introduces a new definition of airspace load and a common computing formula of the airspace utilization rate, and applies them to build the calculation model of the en-route utilization rate.

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