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[Continued on next page]

(54) Title: AIRLINE RESOURCE MANAGEMENT

(57) Abstract: There is described techniques for managing airline resources. A first passenger flow solution is determined corresponding to a first time-space network of flights, the time-space network comprising a plurality of nodes and a plurality of edges, wherein each node has an associated location and an associated time and wherein each edge interconnects two nodes and has an associated cost and an associated passenger capacity. A second passenger flow solution is then determined corresponding to a second time space network of flights using the first passenger flow solution for the first time space network of flights.

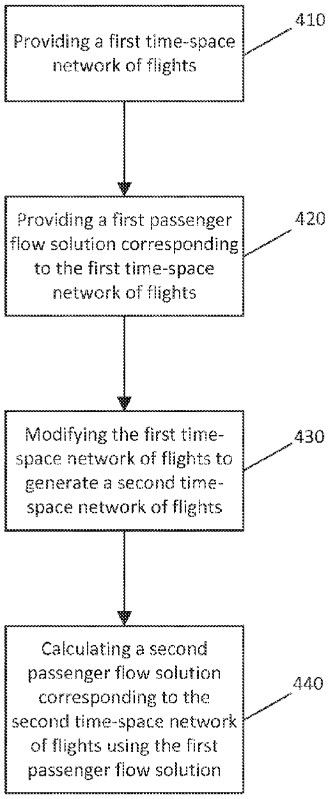

FIG. 4

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AIRLINE RESOURCE MANAGEMENT

BACKGROUND

[0001] In the airline industry, flight plans are made several months before the actual day of operation. The principal resources taken into account when making flight plans are the aircraft, the crew and the passengers. During the planning process, these principal resources are generally considered as separate entities, which are scheduled to a large extent independently with the aim of maximizing revenue.

[0002] There are various reasons why scheduled flight plans may need to be changed. For example, bad weather, aircraft malfunctions and crew absence may each result in a scheduled flight plan needing to be changed. Such flight plan changes often occur right up to the actual day of operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Various features of the present disclosure will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the present disclosure, and wherein:

[0004] Figure 1 is a schematic diagram showing the main components of an apparatus for managing airline resources according to an example;

[0005] Figure 2 is a schematic diagram showing data processing operations according to an example;

[0006] Figure 3 shows a passenger flow solution for an instance of a flight management state space graph according to an example;

[0007] Figure 4 is a flow diagram showing a method of determining a passenger flow solution according to another example;

[0008] Figure 5 is a flow diagram showing in more detail a method of calculating a passenger flow solution using residual networks according to a further example; and

[0009] Figure 6 is a schematic diagram showing a computing device for airline resource management according to an example.

DETAILED DESCRIPTION

[0010] Changing a planned flight schedule is challenging due to the complexity of the re-planning involved. Changing a planned flight schedule on the day of operation is further challenging as a solution may be desired within a few minutes.

[0011] Previous approaches to changing a planned flight schedule have generally involved sequentially addressing the principal resources in the order: aircraft, crew and passenger. This ordering inherently ranks the resources by importance, which can have a negative impact on the resulting solution.

[0012] Certain techniques will now be described in which airline resource management is modelled as a state space, i.e. a set of states that a system can be in, with two states being interconnected if there is an operation that can be performed to transform the first state into the second state. By considering all system states, no hierarchy of importance is imposed on the principal resources. This state space can be represented by a graph in which each node corresponds to a full system solution for which each flight is assigned with a specific plane and specific crew members, and that supplies the requirements of passengers. The resultant state space graph ends up with a large number of states, where each state corresponds to a different instance of the resource assignment.

[0013] Certain examples of the present invention may utilize non-volatile random access memory (NVRAM) technology, for example memristor technology, to handle and maintain the state space graph. In this way, operations on the state space graph can be executed efficiently and quickly.

[0014] Certain examples of the present invention may exploit the fact that adjacent nodes in the state space graph are similar to each other by employing techniques that use the solution for one node when determining the solution for an adjacent node. Such processing allows for efficient computation of the state space graph.

[0015] Figure 1 shows an example of an apparatus 100 for managing airline resources. As shown, the apparatus 100 has a processor 110, memory 120, input devices 130 and output devices 140 interconnected by a data bus system 150. The processor 110 is formed by at least one processing device. The input devices

130, although schematically represented as a single component in Figure 1, may include multiple devices, e.g. a network interface, a keyboard, a touchscreen and a reader for a computer-readable storage medium such as a CD-ROM. Similarly, the output devices 140, although schematically represented as a single component in Figure 1, may include multiple devices, e.g. a display or a network interface.

[0016] In this example, the memory 120 is formed of non-volatile random access memory (NVRAM) and includes program memory 160 storing program code and data memory 170 storing a state space graph for a plurality of flights. The state space graph has a plurality of nodes with each node having a corresponding assignment of aircraft, crew and passengers to each of a plurality of flights. The program code includes a set of instructions that, when executed by the processor 110, determine a passenger flow solution for a node of the state space graph.

[0017] In an example, the state space graph makes use of constraint satisfaction techniques to identify solutions for assigning aircraft and crew to a flight, and then applies a combinatorial approach, based on a minimum cost techniques, to identify passenger flow solutions. As shown in Figure 2 for an example instance, aircraft constraints 200, aircraft resources 210, crew resources 220 and crew constraints 230 are input to constraint satisfaction processing code 240. Aircraft resources 210 provides details of aircraft available for scheduling, for example passenger capacity, and aircraft constraints 200 provides details on restrictions on use of the aircraft, which can include, for example, maintenance requirements. Crew resources 220 provides details of available crew, for example job description (e.g. pilot, steward etc.) while crew constraints 230 can include, for example, maximum hours that a crew member can work in a period of time.

[0018] The constraint satisfaction processing code 240 outputs a time-space network of flights 260 specifying a schedule of flights between a source destination and an end destination. The time-space network of flights 260 stores data for each flight, in which a flight n has a capacity u_n and is scheduled to depart from location X_l at time T_l and to arrive at location X_m at time T_m. The locations X_l and X_m can, for example, correspond to airports. The time-space network of flights 260 forms an input for minimum cost flow analysis code 280. Also forming inputs for the minimum cost flow analysis code 280 are passenger data, in the form of a time-space network of passenger requirements 250, and cost data 270. The time-space network of passenger requirements 250 indicates the passenger travel itineraries that are to be serviced by the scheduled aircraft as specified in the time-space network of flights 260. In the time-space network of passenger requirements 250, a requirement k specifies that Q_k passengers at location X_i at time T_i need to arrive at location X_j at time T_j. The cost data 270 is used to determine airline cost. In this example, the cost data 270 has two factors: a cost c_n for each passenger on flight n and a cost c_p for each unit of delay for each passenger.

[0019] The minimum cost flow analysis code 280 determines how to assign passengers to aircraft, as detailed in the time-space network of flights 250, in such a manner that the passenger requirements, as detailed in the time-space network of passenger requirements, are met without incurring undue cost, as determined using the cost data 270. The minimum cost flow analysis code 280 outputs data, referred to as a passenger flow solution 290, giving passenger numbers for different flights for the instance.

[0020] The manner in which the minimum cost flow analysis code 280 constructs the passenger flow solution 290 from the input data is as follows. For each flight $k = (u_k, X_l, T_l, X_m, T_m)$ in the time-space network of flights 260, the arrival and departure time-space events (X_l, T_l) and (X_m, T_m) are respectively modelled by nodes $(X_l, T_l, 0)$, $(X_l, T_l + 1, 1)$ … $(X_l, T_l + \mathrm{d}, \mathrm{d})$ … $(X_l, T_l + \mathrm{D}, \mathrm{D})$ and the nodes $(X_m, T_m, 0)$, $(X_m, T_m + 1, 1)$ … $(X_m, T_m + \mathrm{d}, \mathrm{d})$ … $(X_m, T_m + \mathrm{D}, \mathrm{D})$, where d is the number of units of delay and D is the maximum number of units of delay for a passenger. For each delay d in [0, D], an edge is formed between the node $(X_l, T_l+\mathrm{d}, \mathrm{d})$ and the node $(X_m, T_m+\mathrm{d}, \mathrm{d})$ with a cost c_n and a passenger capacity u_n. In addition, for each time-space event (X_i, T_i) an edge is formed between consecutive delay time stamps (i.e. between the node $(X_i, T_i + \mathrm{d}, \mathrm{d})$ and the node $(X_i, T_i+\mathrm{d}+1, \mathrm{d}+1)$ for every delay in [0, D-1]) with a cost of c_p and unbounded passenger capacity. For each passenger requirement k in the time-space network of passenger requirements, a flow demand Q_k is assigned for the node $(X_i, T_i, 0)$. Finally, a sink node (X_j, T_j) is formed and edges are added between $(X_j, T_j + \mathrm{d}, \mathrm{d})$ and (X_j, T_j) with zero cost for every d in [0,D]. Minimum cost flow techniques can then be applied to determine a passenger flow solution 290.

[0021] A simple illustrative example is shown in Figure 3, in which flight 1 is scheduled to depart from location X at time 3 and to arrive at location Z at time 14, flight 2 is scheduled to depart from location Y at time 10 and also arrive at location Z at time 14, and the maximum delay is four time units. Each of the nodes 305_1 to 305_15 (collectively referred to as the nodes 305) in Figure 3 represents a combination of a location and a time. For flight 1, the aircraft can be at location X at time 3, represented by node 305_1. As the maximum delay is four time units, the aircraft can also be at location X at times 4, 5, 6 and 7, respectively represented by nodes 305_2 to 305_5. For flight 1, the aircraft can also be at location Z at times 14, 15, 16, 17 and 18, respectively represented by nodes 305_6 to 305_10. For flight 2, the aircraft can be at location Y at times 10, 11, 12, 13 and 14, represented by nodes 305_11 to 305_15, and at location Z at times 14, 15, 16, 17 and 18, respectively represented by nodes 305_6 to 305_10. A sink node 310 is also provided representing an end state in which no further cost is incurred.

[0022] The possible transitions between the nodes 305 and also between the nodes 305 and the sink node 310, cumulatively the edges for the minimum cost flow analysis, are indicated by arrows in Figure 3. As discussed above, there is a cost and a passenger capacity associated with each transition. For transitions in which the location changes, e.g. between node 305_1 and node 305_6, the cost is c_n per passenger and the passenger capacity is u_n, where n is the flight index (i.e. n=1 for flight 1 and n=2 for flight 2). For transition where the location does not change, for example between node 305_1 and node 305_2, the passenger capacity is unbounded and the cost is c_p. For transitions between a node 305 and the sink node 310, the passenger capacity is unbounded and the cost is zero.

[0023] If the passenger requirements specify that Q_1 passengers wish to depart location X at time 3 for destination Z and Q_2 passengers wish to depart location Y at time 10 for destination Z, then the minimum cost flow analysis code identifies a passenger flow solution for Q_1 passengers between the node 305_1 and the sink node 310 and Q_2 passengers between the node 305_11 and the sink node 310. I is straightforward to see that a minimum cost flow solution is for the Q_1 passengers to 'flow' from node 305_1 to node 305_6 and subsequently from node 305_6 to sink node 310, and for Q_2 passengers to 'flow' from node 305_11 to node 305_6 and subsequently from node 305_6 to sink node 310. This passenger flow solution corresponds to flight 1 leaving location X at time 3 and arriving at location Z at time 14, and flight 2 leaving location Y at time 10 and arriving at location Z at time 14 (i.e. flights 1 and 2 operate at their scheduled times). For other instances, the passenger flow solution is not so straightforward.

[0024] Returning to Figure 2, the minimum cost flow analysis code computes a passenger flow solution for each node in the state space graph. In some applications, the computation time for computing a passenger flow solution for each node in the state space graph independently of any other node in the state space graph is longer than the available time in some applications. A technique for reducing the computation time for determining a first passenger flow solution for a first time-space network of flights using a second passenger flow solution for a second time-space network of flights will now be described. This technique takes advantage of two different techniques used when determining minimum cost flow, namely the successive shortest path technique and the cycle-cancelling technique, which make use of residual networks.

[0025] A residual network represents the residual flow capacity between nodes in a network. If G is a network and x is a feasible flow solution for the network G, then if an edge (i, j) has a flow capacity u_{ij} and under the feasible flow solution x carries x_{ij} units of flow, then the residual capacity r_{ij} of the edge x_{ij} is given by $r_{ij} = u_{ij} - x_{ij}$. In other words, the residual capacity r_{ij} of an edge x_{ij} represents the additional units of flow that are able to be sent over the edge x_{ij}. In contrast, the flow x_{ij} can be reduced by sending up to x_{ij} units of flow from j to i over the edge (i,j). Sending a unit of flow from i to j along the edge (i,j) increases the cost function by c_{ij}, whereas sending a unit of flow from j to i on the same edge reduces the cost function by c_{ij}. Based on these concepts, the residual network for the network G with respect to a flow solution x corresponds to replacing each edge (I,j) in G with two edges (i,j) and (j,i): the edge (i,j) having a cost c_{ij} and a residual capacity $r_{ij} = u_{ij} - x_{ij}$, and the edge (j,i) having a cost $-c_{ij}$ and a residual capacity $r_{ji} = x_{ij}$.

[0026] The successive shortest path technique simultaneously searches for a maximum flow and reduces the cost function. Instead of searching for the classical maximum flow, the successive shortest path technique sends flow from a source node to a sink node along the shortest path with respect to link costs. The successive shortest path technique then determines the residual network for that solution, identifies an augmenting path and augments the flow along the augmenting path in the residual network. The successive shortest path technique then finds a new shortest path with respect to link costs, updates the residual network and augments the flow in the residual network. This process continues iteratively until the flow requirement is satisfied.

[0027] The cycle cancelling technique is based on a different approach to determining minimum cost flow. In the following, negative cycle optimality conditions, and as a consequence the cycle cancelling technique, will be explained. A theorem states that if x^* is a feasible solution in a minimum cost flow analysis, then x^* is an optimal solution if the residual network $G(x^*)$ contains no negative cost directed cycle. Accordingly, an approach to minimum cost flow analysis is to use any maximum flow technique to establish a feasible solution, and then use the cycle cancelling technique to find negative cost cycles in the residual network and then augment the flow along those negative cycles until no negative cost directed cycle exists.

[0028] Figure 4 illustrates a minimum cost flow technique that can be implemented by the apparatus shown in Figure 1. The operations illustrated in Figure 4 can be performed by the minimum cost flow analysis code 280 illustrated in Figure 2, which forms part of the program code 160 illustrated in Figure 1. As shown in Figure 4, a method of minimum cost flow analysis involves providing, at 410, a first time-space network of flights and providing, at 420, a first passenger flow solution corresponding to the first time-space network of flights. The first time-space network of flights is then modified, at 430, to generate a second time-space network of flights and the a second passenger flow solution is calculated, at 440, for the second time-space network of flights using the first passenger flow solution corresponding to the first time-space network of flights.

[0029] Figure 5 shows in more detail the calculation of the second passenger flow solution as represented by 440 in Figure 4. As shown in Figure 5, the calculation of the second passenger flow solution involves determining, at 510, a residual network associated with the first passenger flow solution and establishing, at 520, a feasible flow in the second time-space network of flights. The feasible flow in the second passenger flow solution is calculated by taking each modification one edge at a time, so that the two instances of the minimum cost flow technique differ from each other by a single edge (i,j). In other words, the two instances of the minimum cost flow technique can differ either by virtue of the absence of a link in the second instance (corresponding to deleting an edge interconnecting a first node and a second node in the time-space network of flights associated with the first passenger flow solution, or by virtue of the presence of an additional link in the second instance, (corresponding to adding an edge interconnecting a first node and a second node in the time-space network of flights associated with the first passenger flow solution) .

[0030] If the second time-space network of flights misses a link (i,j) with respect to the first time-space network of flights, then the residual network for the first passenger flow solution must be updated to cancel the flow over the edge (i,j) to form a feasible passenger flow solution for the second time-space network of flights. This is achieved by sending flow from the node i to the source node s over the shortest available path in the residual network and sending flow from the node j to the sink node t over the shortest available path in the residual network. In contrast, if the second time-space network of flights includes an additional link (i,j) then the first passenger flow solution forms a feasible passenger flow solution for the second time-space network of flights.

[0031] After establishing a feasible passenger flow, the flow in the residual network for the time-space network of flights is augmented, at 530, and the residual network is revised, at 540, accordingly. It is then checked if there is any negative cost directed cycle in the residual network (at 550). If there is, then the passenger flow is further augmented along negative cost directed cycles in the residual network, and the residual network revised accordingly in an iterative manner. If there are no negative cost directed cycles in the residual network, then a passenger flow solution for the second time-space network of flights has been reached.

[0032] In certain examples, the crew and aircraft assignment changes with the transition from state to state in the state space graph and a passenger flow assignment is determined as a solution for each state. The combinatorial approach using minimum cost flow analysis is well suited to the flow dynamics and non-specific properties of the passenger travel requirements.

[0033] Certain system components and methods described herein may be implemented by way of non-transitory computer program code that is storable on a non-transitory storage medium. Figure 6 shows an example 600 of a system 600 comprising at least one processor 610 arranged to retrieve data from a computer readable storage medium 620. The computer-readable storage medium 620 comprises a set of computer-readable instructions 630 stored thereon. The set of computer readable instructions are arranged to cause the at least one processor to perform a series of actions. Instruction 640 is arranged to determine a passenger flow solution corresponding to a first time-space network of flights, the first time-space network of flights comprising a plurality of nodes and a plurality of edges, wherein each node has an associated location and an associated time and wherein each edge interconnects two nodes and has an associated cost and an associated passenger capacity. Instruction 650 is arranged to determine a second passenger flow solution corresponding to a second time-space network of flights using the first passenger flow solution for the first time-space network of flights.

[0034] The non-transitory storage medium can be any media that can contain, store, or maintain programs and data for use by or in connection with an instruction execution system. Machine-readable media can comprise any one of many physical media such as, for example, electronic, magnetic, optical, electromagnetic, or semiconductor media. More specific examples of suitable machine-readable media include, but are not limited to, a hard drive, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory, or a portable disc.

[0035] The preceding description has been presented to illustrate and describe examples of the principles described. This description is not intended to be exhaustive or to limit these principles to any precise form disclosed. Many modifications and variations are possible in light of the above teaching. Techniques, functions and approaches described in relation to one example may be used in other described examples, e.g. by applying relevant portions of that disclosure.

What is claimed is:

1. A computer-implemented method for managing airline resources, the method comprising:

providing a first time-space network of flights, the time-space network comprising a plurality of nodes and a plurality of edges, wherein each node has an associated location and an associated time and wherein each edge interconnects two nodes and has an associated cost and an associated passenger capacity;

providing a first passenger flow solution corresponding to the first time space network of flights;

modifying the first time-space network of flights to generate a second time space network of flights; and

calculating a second passenger flow solution corresponding to the second time space network of flights using the first passenger flow solution for the first time space network of flights.

2. A computer-implemented method according to claim 1, wherein the calculation of the second passenger flow solution comprises:

determining a residual network associated with the first passenger flow solution;

establishing a feasible flow in the second time space network of flights and revising the residual network accordingly; and

iteratively augmenting flow in the time space network of flights and revising the residual network accordingly.

3. The computer implemented method of claim 2, wherein the iterative augmenting of flow in the time space network of flights and the revising of the residual network accordingly terminates when the residual network contains no negative cost directed cycle.

4. The computer-implemented method of claim 2, wherein:

the modification of an edge of the time space network of flights comprises deleting an edge interconnecting a first node and a second node; and

the establishing of a feasible flow comprising cancelling flow over the deleted edge by sending flow from the first node to the source node and by sending flow from the second node to a sink node along the respective shortest paths.

5. The computer-implemented method of claim 2, wherein:

the modification of an edge of the time space network of flights comprises adding an edge interconnecting a first node and a second node; and

the establishing of a feasible flow comprises adopting the solution for flow between the source node and the sink node determined for the time space network of flights before modification.

6. The method of claim 1, wherein providing the first time-space network of flights comprises:

receiving aircraft data for at least one aircraft, the aircraft data specifying at least one constraint;

receiving crew data for crew members, the crew data specifying at least one constraint; and

processing the aircraft data and the crew data using a constraint satisfaction technique to generate the first time-space network of flights.

7. The method of claim 6, wherein providing the first passenger flow solution comprises:

receiving passenger data specifying passenger travel itineraries; and

calculating the first passenger flow solution in accordance with the first time-space network of flights and the passenger data using a minimum cost technique.

8. Apparatus for managing airline resources, the apparatus comprising:

a processor;

data memory storing a state space graph for a plurality of flights, each node of the state space graph corresponding to an assignment of aircraft, crew and passengers to each of the plurality of flights; and

program memory storing a set of instructions which, when executed by the processor, determine a passenger flow solution for a first node of the state space graph using a passenger flow solution for a second node of the state space graph.

9. Apparatus according to claim 8, wherein the non-volatile random access memory comprises a plurality of memristors.

10. Apparatus according to claim 8, wherein the set of instructions is arranged to:

determine a residual network associated with the passenger flow solution for the second node;

establish a feasible passenger flow solution for the first node and revise the residual network accordingly; and

iteratively augment passenger flow for the first node and revise the residual network accordingly.

11. Apparatus according to claim 10, wherein the first node of the state space graph differs from the second node of the state space graph by a single edge within a time-space network of flights.

12. Apparatus according to claim 11, wherein the first node of the state space graph differs from the second node of the state space graph by the absence of an edge within the time-space network of flights, and wherein the set of instructions is arranged to establish the feasible passenger flow solution by cancelling flow over the absent edge in the passenger flow solution for the second node.

13. Apparatus according to claim 11, wherein the difference between the first node of the state space graph and the second node of the state space graph

corresponds to the presence of an additional edge, wherein the feasible passenger flow solution corresponds to the passenger flow solution for the second node.

14. A non-transitory computer-readable storage medium comprising a set of computer-readable instructions stored thereon, which, when executed by a processor, cause the processor to:

determine a passenger flow solution corresponding to a first time-space network of flights, the first time-space network of flights comprising a plurality of nodes and a plurality of edges, wherein each node has an associated location and an associated time and wherein each edge interconnects two nodes and has an associated cost and an associated passenger capacity; and

determine a second passenger flow solution corresponding to a second time-space network of flights using the first passenger flow solution for the first time space network of flights.

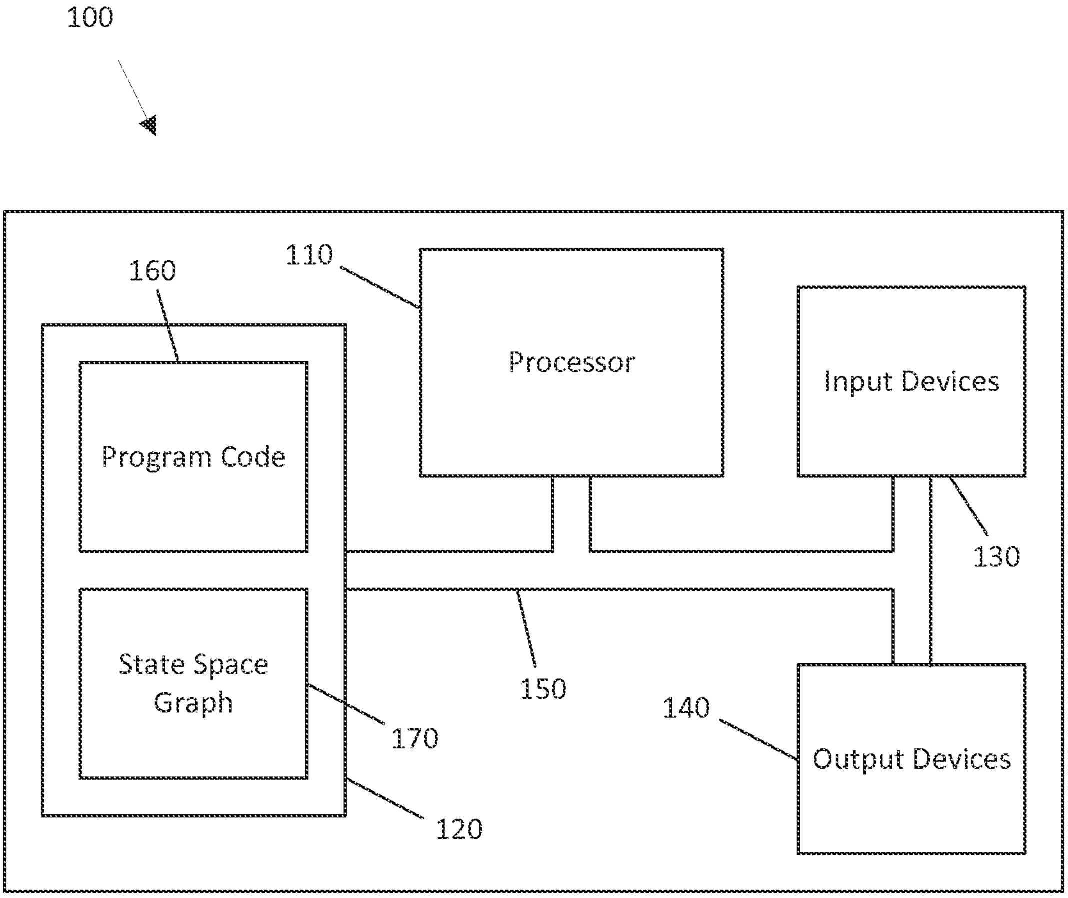

100
110
Processor
Input Devices
130
160
Program Code
State Space Graph
170
150
140
Output Devices
120

FIG. 1

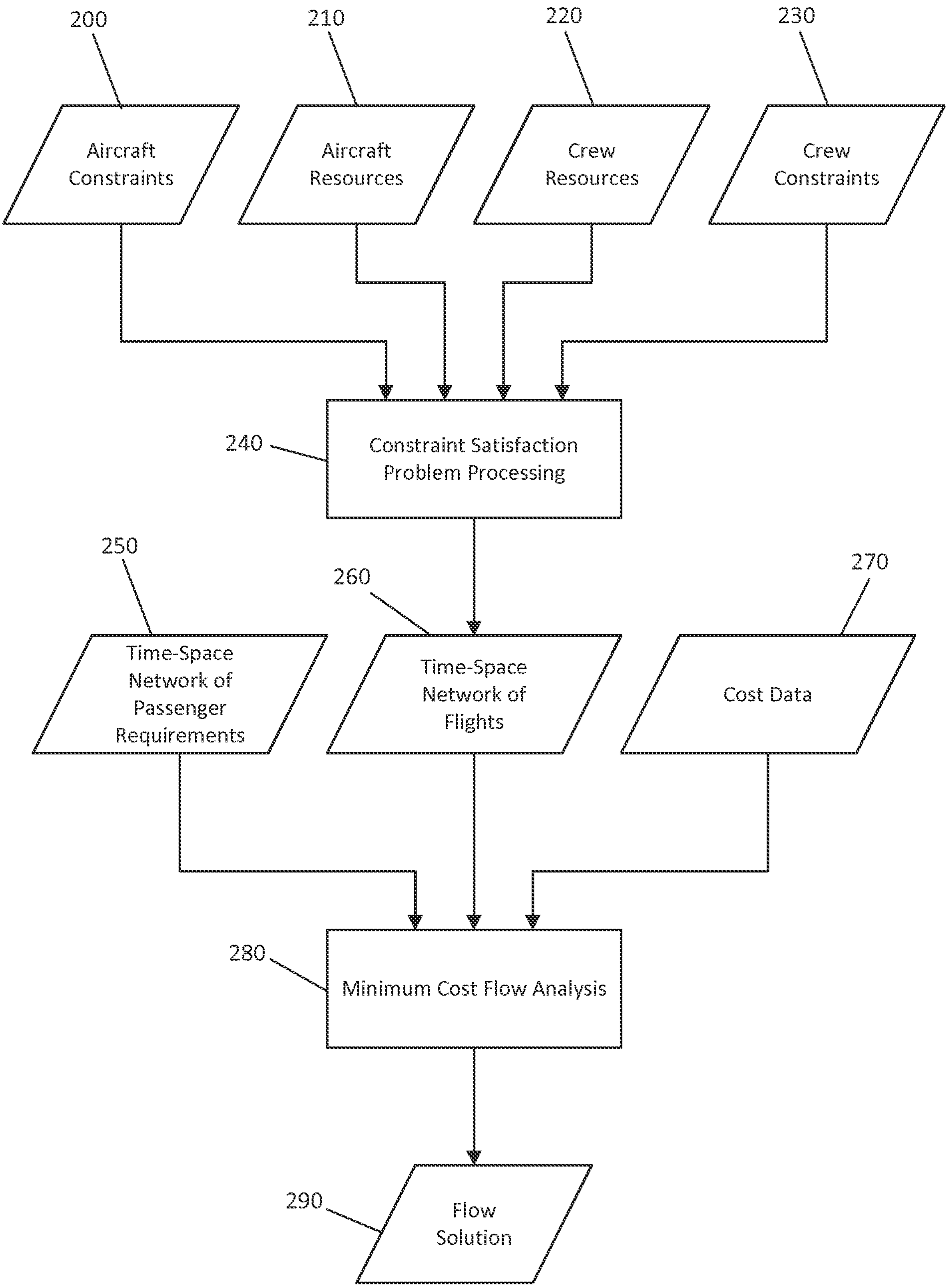
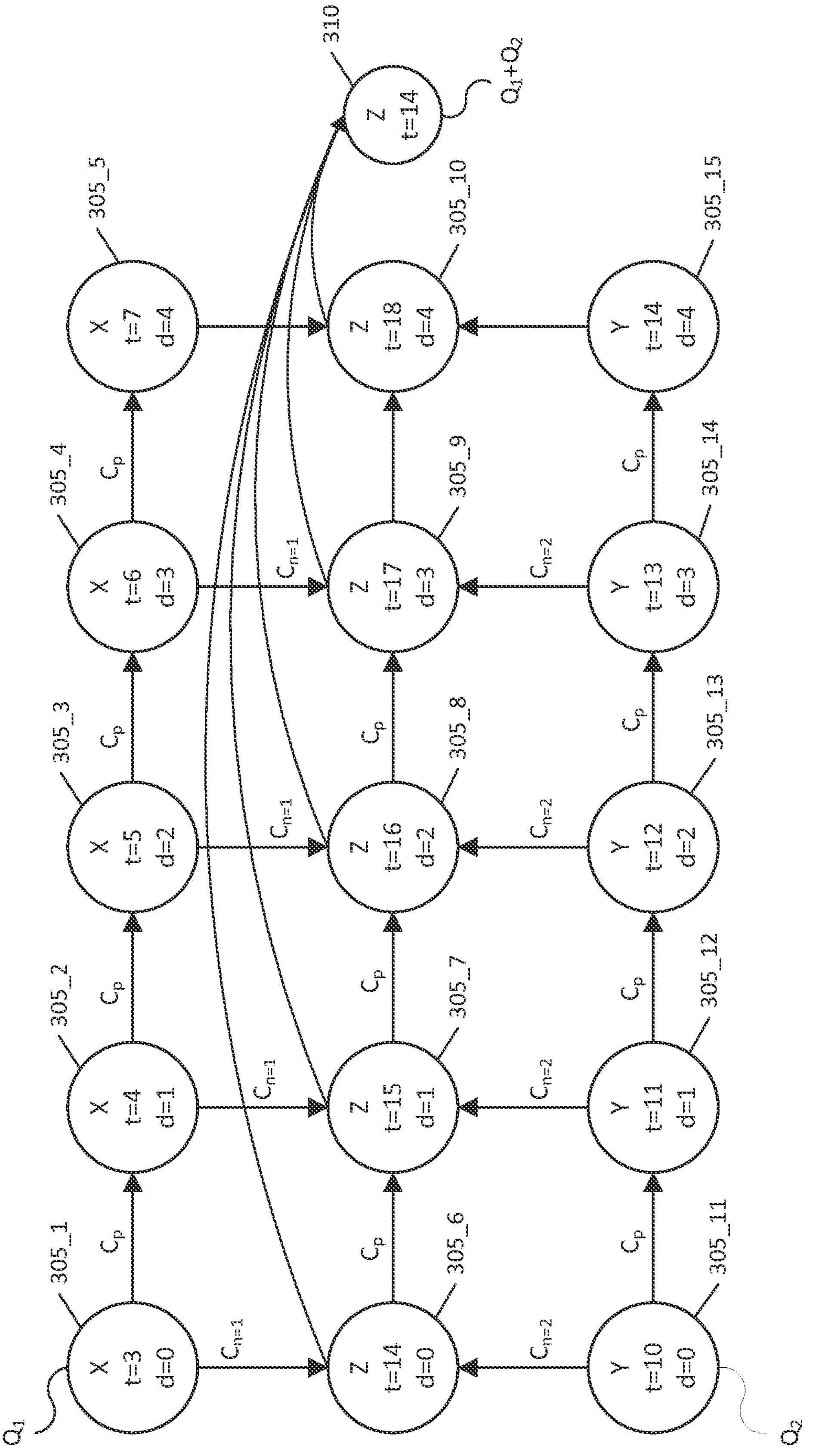

200
210
220
230
Aircraft Constraints
Aircraft Resources
Crew Resources
Crew Constraints
240
Constraint Satisfaction Problem Processing
250
260
270
Time-Space Network of Passenger Requirements
Time-Space Network of Flights
Cost Data
280
Minimum Cost Flow Analysis
290
Flow Solution

FIG. 2



310
Z
t=14
Q_1+Q_2
305_1
X
t=3
d=0
Q_1
305_2
X
t=4
d=1
305_3
X
t=5
d=2
305_4
X
t=6
d=3
305_5
X
t=7
d=4
305_6
Z
t=14
d=0
305_7
Z
t=15
d=1
305_8
Z
t=16
d=2
305_9
Z
t=17
d=3
305_10
Z
t=18
d=4
305_11
Y
t=10
d=0
Q_2
305_12
Y
t=11
d=1
305_13
Y
t=12
d=2
305_14
Y
t=13
d=3
305_15
Y
t=14
d=4
C_p
$C_{n=1}$
$C_{n=2}$

FIG. 3

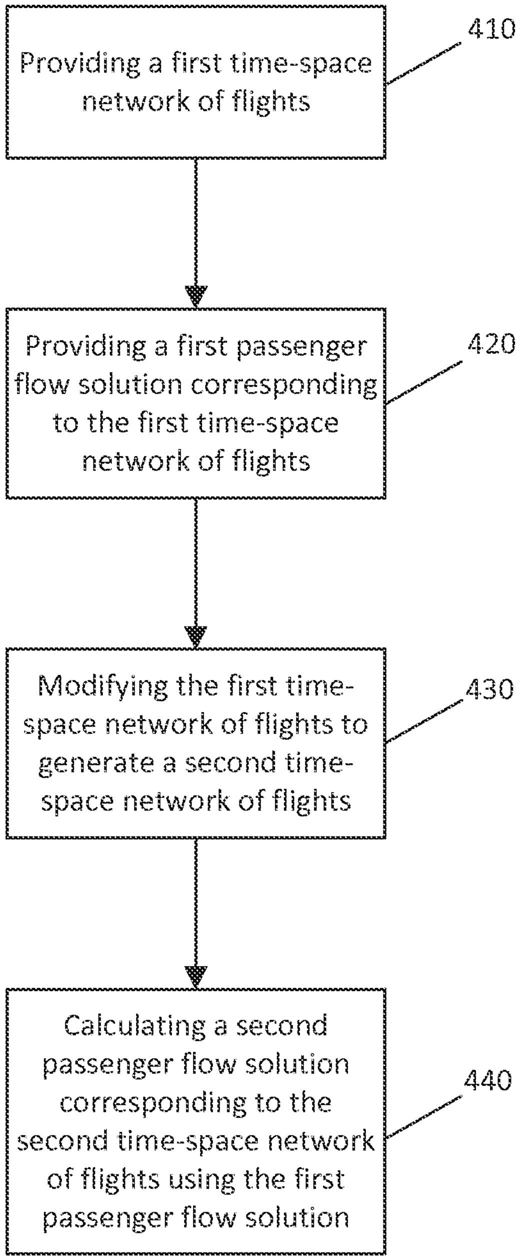

Providing a first time-space network of flights
410
Providing a first passenger flow solution corresponding to the first time-space network of flights
420
Modifying the first time-space network of flights to generate a second time-space network of flights
430
Calculating a second passenger flow solution corresponding to the second time-space network of flights using the first passenger flow solution
440

FIG. 4

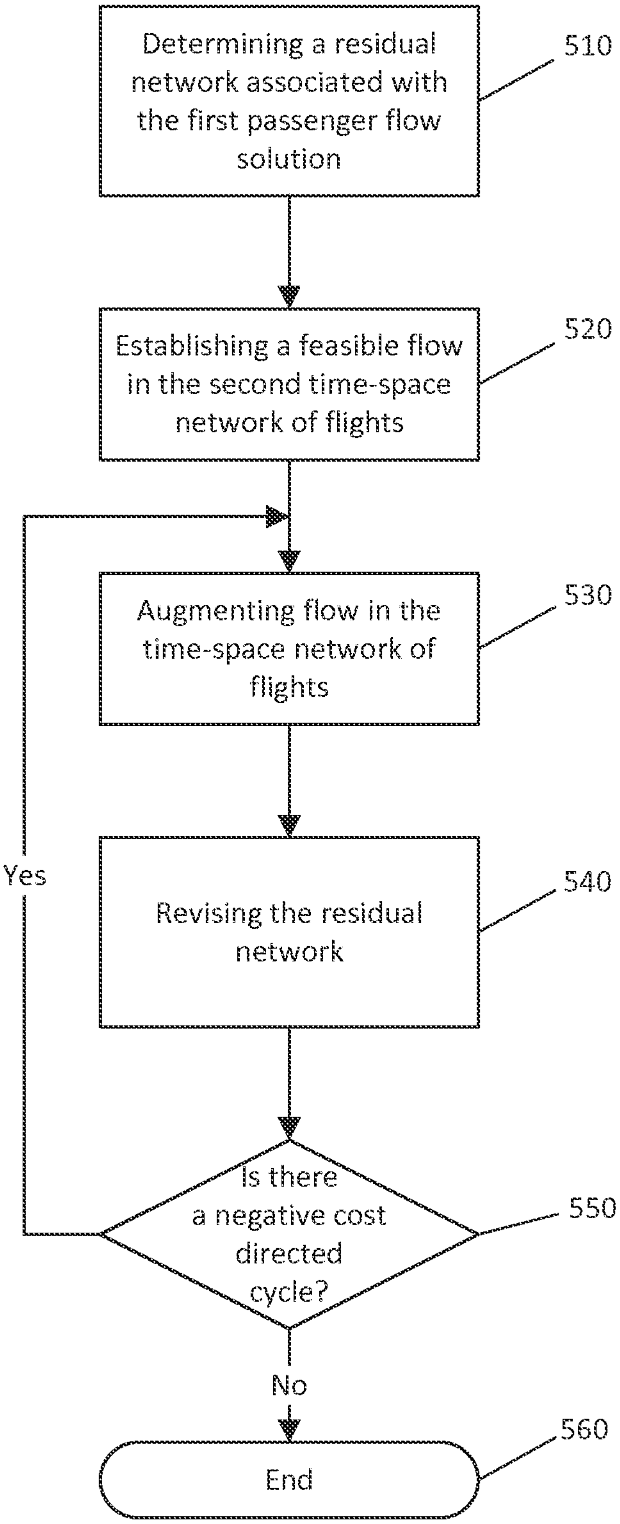

Determining a residual network associated with the first passenger flow solution
510
Establishing a feasible flow in the second time-space network of flights
520
Augmenting flow in the time-space network of flights
530
Revising the residual network
540
Yes
Is there a negative cost directed cycle?
550
No
End
560

FIG. 5

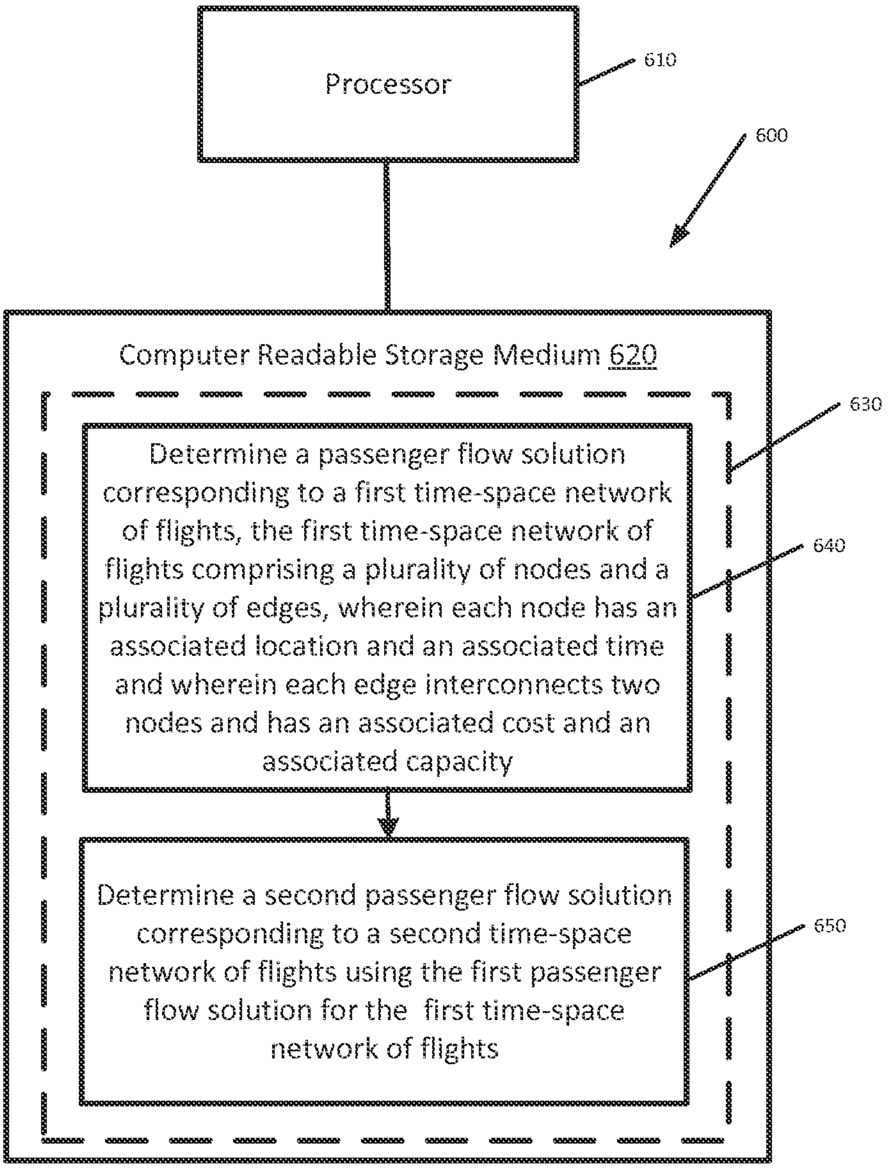

Processor
610
600
Computer Readable Storage Medium 620
630
Determine a passenger flow solution corresponding to a first time-space network of flights, the first time-space network of flights comprising a plurality of nodes and a plurality of edges, wherein each node has an associated location and an associated time and wherein each edge interconnects two nodes and has an associated cost and an associated capacity
640
Determine a second passenger flow solution corresponding to a second time-space network of flights using the first passenger flow solution for the first time-space network of flights
650

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/044293

A. CLASSIFICATION OF SUBJECT MATTER

G06Q 50/30(2012.01)i, G06Q 10/02(2012.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06Q 50/30; G05B 19/418; G08G 5/00; G06Q 10/00; G06Q 10/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: airline, resource, time space network, flight, node, edge, modify, solution, flow

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010-0082394 A1 (JULIAN PACHON et al.) 01 April 2010 See abstract, paragraphs [0010], [0032], [0036], [0040], [0059]-[0061], [0070], [0072], [0079]-[0080], [0086]-[0106], [0117]-[0118], [0122], [0134]-[0137], claims 1, 11 and figures 1-8.	1-14
Y	US 2014-0012490 A1 (GE AVIATION SYSTEMS LIMITED) 09 January 2014 See abstract, paragraphs [0015]-[0018], [0022], [0025], [0033], [0037], [0042], claim 1 and figures 2-3.	1-14
A	US 2010-0082383 A1 (JULIAN PACHON et al.) 01 April 2010 See abstract, paragraphs [0087]-[0090], [0101], claims 1-3 and figures 1-8.	1-14
A	US 2007-0214033 A1 (H. ROY MILLER) 13 September 2007 See abstract, paragraphs [0025]-[0031], [0046]-[0058], claims 1-5 and figures 1-8, 10, 14.	1-14
A	KR 10-2011-0123101 A (INCHONINTERNAT AIRPORT CORP.) 14 November 2011 See abstract, claims 1-6 and figures 1, 9-11.	1-14

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 27 April 2016 (27.04.2016)	Date of mailing of the international search report **28 April 2016 (28.04.2016)**
Name and mailing address of the ISA/KR International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea Facsimile No. +82-42-481-8578	Authorized officer LEE, Myung Jin Telephone No. +82-42-481-8474

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/044293

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010-0082394 A1	01/04/2010	AU 2009-222493 A1	15/04/2010
		AU 2009-222493 B2	29/01/2015
		CA 2680906 A1	01/04/2010
		CN 101714237 A	26/05/2010
		EP 2172891 A1	07/04/2010
US 2014-0012490 A1	09/01/2014	BR 102012028498 A2	20/05/2014
		CA 2795598 A1	24/05/2013
		CN 103136967 A	05/06/2013
		DE 102012111194 A1	29/05/2013
		FR 2983333 A1	31/05/2013
		GB 2496883 A	29/05/2013
		JP 2013-175157 A	05/09/2013
		US 2013-0138332 A1	30/05/2013
		US 8554459 B2	08/10/2013
		US 8825360 B2	02/09/2014
US 2010-0082383 A1	01/04/2010	AU 2009-222494 A1	15/04/2010
		AU 2009-222494 B2	24/04/2014
		CA 2680660 A1	01/04/2010
		CN 101714228 A	26/05/2010
		EP 2172892 A1	07/04/2010
		US 8645177 B2	04/02/2014
US 2007-0214033 A1	13/09/2007	AU 2007-217832 A1	30/08/2007
		BR PI0708099 A2	17/05/2011
		CA 2642742 A1	30/08/2007
		CA 2675174 A1	24/07/2008
		CN 101421753 A	29/04/2009
		EP 1987482 A2	05/11/2008
		EP 1987482 A4	20/04/2011
		EP 2115644 A2	11/11/2009
		JP 2009-527857 A	30/07/2009
		KR 10-2008-0098538 A	10/11/2008
		MX 2008010680 A	27/01/2009
		US 2008-0059273 A1	06/03/2008
		US 8260650 B2	04/09/2012
		WO 2007-098161 A2	30/08/2007
		WO 2007-098161 A3	21/02/2008
		WO 2008-088387 A2	24/07/2008
		WO 2008-088387 A3	23/10/2008
KR 10-2011-0123101 A	14/11/2011	KR 10-1124829 B1	26/03/2012