Tolerant join operation in a relational database

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Abstract[1]

The basic concept of tolerant join operation in a relational database is reported. Algorithms used to resolve whole class of tasks of potential conflict situation avoidance during preliminary flight planning process on standard flight routes which are overlapping with prohibited areas of different dedication are described. A function model of standard flight routes planning process is presented. An example of database tables filling and solution of the tasks of detection and prevention of potential conflict situations by means of database processing are presented. Authors use algebraic formulas based on relational algebra and names of tables and attributes for description of examined databases processing algorithms. Capabilities of databases systems technology to detect and prevent a potential conflict situation are shown.

1. Introduction

An experience of databases systems technology shows that speed, accuracy and adequacy of preliminary flight planning (PFP) process depends not only on hardware and software capabilities but on ideology (concept) of databases system (DBS) architecture also. We shall not scrutinize DBS conceptual schemata design but use only results of this process for demonstration example, which represents specifics of methodology, described in [1]. We shall concentrate main attention to the description of algorithms used to resolve a whole class of tasks of potential conflict situation (PCS) avoidance during PFP process on standard flight routes (SFR) which are overlapping with prohibited areas (PA) of different dedication. These tasks are called PFP tasks without PCS for aircraft.

2. Function model of SFR planning process

Let us presume that PFP of aircraft between cities A, B, C, D and E is accomplished on everyday basis for 4 routes, represented on figure 1.

Every of this SFR has unique number (NR_SFR), airport of departure (ARP_DEP), airport of destination (ARP_DES) and are determined by necessary number of route points (RP) with unique for given route numbers (NUM_RP) incrementing from the beginning to the end of the route, types (TYPE_RP) and geographic coordinates (LAT_RP —latitude, LON_RP — longitude). Let us consider, that name TYPE_RP may accept following meanings: IRP — initial route point, MRP — intermediate route point, FRP — final route point, ai — contact point of a route with a PA number *i*; en_ai or ex_ai — points of enter or exit to/from PA number *i*.

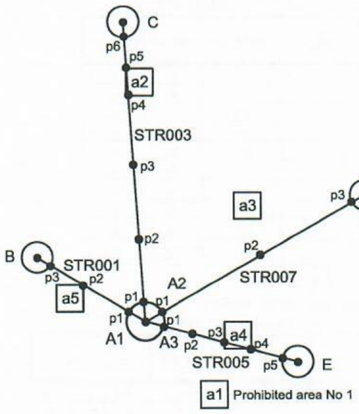

Fig. 1. SFR schema example

Standard routes may cross PAs, which have unique numbers (NUM_A), names (NAM_A) and predestination (PDN_A). Every PA is determined by some number of points (more than 2) of its limits which have unique for given area numbers (NUM_LP) and geographic coordinates (LAT_LP, LON_LP). In the limits of every PA may be assigned several working periods during which flights of airplanes through the PA and in contact with it are restricted. These working periods have unique in a given date numbers (NUM_WP), setting time (ST_R) and cancellation time (CT_R).

The essence of examined task of preventing of PCS with PA is to avoid planning of aircraft flights through PA in time of their working periods.

If and t_c — times of settinng and cancellation of working periods of some PA, and and t_{ext} — times of flight through entrance and exit points of given PA, than conditions of existence or absence of PCS for given PA are the following:

$$((t_{ent} < t_s)\&(t_{ent} < t_s))\vee(t_{ent} > t_c) \text{ — no conflict} \quad (1)$$

$$((t_{ent} < {}_s)\&t_{ent} \geq t_s))\vee(t_s \leq t_{ent} \leq t_c) \text{ — conflict exists} \quad (2)$$

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A setting and cancellation times of every working periods for every PA, times of crossing of entry and exit points of PA by aircrafts calculated manually or by means of special software on a basis of knowledge of departure time (DPT), type of airplanes (TYP_APL) and other parameters of planned flight by given route are saved in a database in a process of its support.

3. An example of database tables filling

We shall use relational database model for description of DBS used in the PFP process. The fragment of filling of a part of DBS meant for setting of PA, determination of their limits and working periods is shown on figure 2.

PA: PROHIBITED AREAS

NUM_A	NAME_A	DED_A
a1	tfa1	tf
a2	f_AD1	t_ff
a3	sfa1	af
a4	tfa2	tf
a5	tfa3	tf

LPPA: LIMIT POINTS OF PROHIBITED AREAS

NUM_A	NUM_LP	LAT_LP	LON_LP
a2	lp1	x_1	y_1
	lp2	x_2	y_2
	lp3	x_3	y_3
	lp4	x_4	y_4
a4	lp1	x_5	y_5
	lp2	x_6	y_6
	lp3	x_7	y_7
	lp4	x_8	y_8
a5	lp1	x_9	y_9
	lp2	x_{10}	y_{10}

WPPA: WORKING PERIODS OF PROHIBITED AREAS

NUM_A	DATE_A	NUM_PC	TB_C	TE_C
a2	20.09.2008	wp1	09.30	10.30
		wp2	19.00	20.00
a4	20.09.2008	wp1	08.00	09.00
		wp2	18.00	19.00
a5	20.09.2008	wp1	09.00	10.30
		wp2	22.00	23.00

Fig. 2. Fragment of PA database

A composition of the tables included in this DBS (tables names, composition and names of attributes, attribute name values, rules of filling of the tables by specific values and tables relationships) are determined at a stage of DBS design.

We shall use the following semantic meanings of attribute names for a simplified description of an examined database fragment: ai — PA number *i*; alpj — PA number *j*; tfai — training flight area number *i*; sfai — sport flight area number *i*; tf—training flights; af— aerobatic flights; 20.09.2008 — date in format of (dd.mm.yyyy) —day, month, year; wpi — working period number *i*; 19.00 — date in format of (hh.mm) — hours, minutes.

Fragment of another part of DBS filling, which reflects a standard route flights planning process are represented by means of tables **STR**, **RP**, **STRF**, **RPOF** (see figure 3). Relationships between tables determine an order of their filling which is scrutinized in [1].

An essence of flights planning process is to set date of flight (DATE_F), time of departure (TM_DEP), type of airplane (TYP_AP), crew's call sign (CCS) and number of standard route (STR_NUM) which is planned to use for given flight. This process is connected with a record of relevant data into the table **STRF**. After that manually or by means of special software on a basis of data about an airplane type (TYP_AP) with help of some method are calculated: times (TC_RP), heights (HC_RP) and true speeds (TS_RP) of standard routes points crossing.

There are omissions of repeated values of attributes in some rows of the tables. It was done purposely for better understanding of these tables semantic. In real these positions include the same data as in the closest upper row of a table.

It may be considered that examined example is related with the two databases, the one shown on figure 2 and the other on figure 3. These databases have no common attributes and, on the other hand, may be filled (updated) independently from each other. On the other hand, they have differently named attributes with equal values "date" (names DATE_F and DATE_A) and similar (tolerant) values (names NUM_A and TYPE_RP). As will be shown below, existence of such attributes provides opportunity for mutual processing of these databases tables for the purpose of data mining with the goal of resolving a task of PCS avoidance in preliminary flight plans.

Examined database tables are filled for better understanding only on date 20.09.2008 and only for certain PAs and certain route points. In reality DBS consist of completely filled tables.

A software, which process these databases for the purpose of PCS avoidance with PAs, must determine evidence of potential conflict (EPC) for every planned flight. Values of this attribute (0 — no conflict, 1 — conflict exists) have sense and may be determined only for route points, which cross PAs. The existence of potential conflict in the flight plan (after its detection) may be marked by coloring or by flashing of corresponding rows in the tables **FSTR** and **OFRP**, or in the other exit forms, which are used by flight planner, forcing him to produce certain changes in the flight plan with the purpose of avoidance of detected PCS.

In the examined example of flight plan there exist but are not seen explicitly the PCSs for 3 flight crews with call sign C15 on the route STR005, C99 on the route STR001 and C50 on the route STR003 which is marked by bold type of relevant rows in the tables **FSTR** and **OFRP**. For example, the PCS for flight crew C50 is determined by the fact that this flight by crossing PA number a2 violates some of its working periods. In the examined DBS (figures 2 and 3) are included all necessary information for explicit detection of PCSs but real picture of these

PCSs which contains their sources of originations, working times and areas, in the limits of which they arose, necessary actions should be taken to prevent them are implicit.

STRF: STANDARD ROUTS FLIGHTS

DATE_F	NUM_STR	CCS	TM_DEP	TM_ARV	TYP_AP
20.09.2008	STR005	C07	10.05	11.25	Yak-40
	STR005	**C15**	**18.00**	**19.20**	**Yak-40**
	STR001	**C99**	**09.45**	**10.45**	**Tu-154**
	STR001	C77	11.50	12.50	Tu-154
	STR003	**C50**	**07.25**	**11.25**	**An-12**
	STR003	C37	15.30	19.30	An-12

STR: STANDARD ROUTES

NUM_STR	ARP_DEP	ARP_ARV
STR001	A1	B
STR005	A3	E
STR003	A1	C
STR007	A2	D

RP: ROUTE POINTS

STR_NUM	NUM_RP	LAT	LON	TYP_RP
STR003	p1	x_1	y_1	SRP
	p2	x_2	y_2	IRP
	p3	x_3	y_3	IRP
	p4	x_4	y_4	ent_a2
	p5	x_5	y_5	ext_a2
	p6	x_6	y_6	FRP
STR005	p1	x_7	y_7	SRP
	p2	x_8	y_8	IRP
	p3	x_9	y_9	ent_a4
	p4	x_{10}	y_{10}	ext_a4
	p5	x_{11}	y_{11}	FRP
STR001	p1	x_{12}	y_{12}	SRP
	p2	x_{13}	y_{13}	a5
	p3	x_{14}	y_{14}	FRP

RPOF: ROUTE POINS OVERFLIGHT

DATE_F	NUM_STR	CCS	NUM_RP	TC_RP	H_RP	TS_RP
20.09.2008	STR005	C07	p3	10.56	7000	600
			p4	11.08	7000	600
		C15	**p3**	**18.51**	**7000**	**600**
			p4	**19.03**	**7000**	**600**
	STR003	**C50**	**p4**	**09.25**	**6000**	**500**
			p5	**09.37**	**6000**	**500**
		C37	p4	18.10	6000	500
			p5	18.22	6000	500
	STRM001	**C99**	**p2**	**10.15**	**9000**	**850**
		C77	p2	12.20	9000	850

Fig. 3. An example of information model instance of standard routes flight plan

Let us examine how to solve the tasks of detection and prevention of PCS by means of database processing.

4. Algorithm of detection and prevention of PCS

We shall use algebraic formulas based on relational algebra and names of tables and attributes for description of databases processing algorithms. The results will be presented in a form of corresponded summary tables which may be included into a DBS or may have status of separate record cluster. Our purpose is only to show capabilities of DBS technology to detect and prevent a PCS.

We shell represent a sequence of database processing stages during PFP process in a form of contextual and formal description of sequence of 4 requests (R1—R4) applied to a DBS. The formal algebraic descriptions of information requests in essence are the descriptions of relevant algorithms of data search.

R1. Contextual formulation of request

For all standard routes (NUM_STR) from the table **RP** determine (find) numbers (NUM_RP) and types (TYPE_RP) of route points which are cross points (TYPE_RP = ent ai or ext ai) or contact points (TYPE_RP = ai) with the limits of PAs. The result should be presented by the table "Route points on the limits of PAs"

RPLPA (NUM_STR, NUM_RP, TYPE_RP).

Formal notation of request in a form of algebraic expression

$$\mathbf{RPLPA} = \pi_{\mathrm{NUM\_STR,\ NUM\_RP,\ TYPE\_RP}}(\sigma_{\mathrm{TYPE\_RP} = \mathrm{ent\ ai} \vee \mathrm{ext\ ai} \vee \mathrm{ai}}(\mathbf{RP}))$$

prescribes producing of selection operation (σ) of table rows which have in the column TYPE_RP one of the values ent ai, ext ai and leaving in the resulting table only 3 columns from initial table: NUM_STR, NUM_RP, TYPE_RP (projection operation — π).

Having done these operations database management system will form prescribed by the algebraic formula table **RPLPA** (figure 4).

RPLPA: ROUTES POINTS ON LIMITS OF PROHIBITED AREAS

NUM_STR	NUM_RP	TYPE_RP
STR003	p4	ent_a2
	p5	ext_a2
STR005	p3	ent_a4
	p4	ext_a4
STR001	p2	a5

Fig. 4. Result of selection and projection operations applied on table RP

R2. Contextual formulation of request

For all standard routes which have cross or contact points with PAs (table **RPLPA**) determine for every such points the periods (NUM_PC) and the times (TB_C, TE_C) of closing of relevant areas on every flight days. The result should be presented by the table "Periods of route points closing on limits of PAs"

PCRPLPA(NUM_STR, NUM_RP, TYPE_RP, NUM_PA, DATE_PA, NUM_PC, TB_C, TE_C).

Formal notation of request in a form of algebraic expression

$$\mathbf{PCRPLPA} = \mathbf{RPLPA}[\mathrm{TYPE\_RP} = (\mathrm{ent\ ai} \vee \mathrm{ext\ ai} \vee \mathrm{ai})\ \&\ \mathrm{NUM\_C} = \mathrm{ai}]\mathbf{WPPA}$$

prescribes producing of examined in this paper of tolerant join operation of rows of table **RPLPA**, which have in their values or in the end of values of attribute TYPE_RP symbols ai with rows of table **WPPA** from the database of PAs, which have in values of attribute NUM_PA the same combination of symbols ai. This is not an ordinary natural join of rows but a join based on resemblance of values (existence of common combination of symbols).

Having done these operations database management system will form prescribed by the algebraic formula table **PCRPLPA** (figure 5).

PCRPLPA: PERIOD OF CLOSING OF POINTS ON LIMITS OF PROHIBITED AREAS

NUM_STR	NUM_RP	TYPE_RP	NUM_PA	DATE_C	NUM_PC	TB_C	TE_C
STR003	p4	ent_a2	a2	20.09.2008	p1	09.30	10.30
					p2	19.00	20.00
	p5	ext_a2	a2	20.09.2008	p1	09.30	10.30
					p2	19.00	20.00
STR005	p3	ent_a4	a4	20.09.2008	p1	08.00	09.00
					p2	18.00	19.00
	p4	ext_a4	a4	20.09.2008	p1	08.00	09.00
					p2	18.00	19.00
STR001	p2	a5	a5	20.09.2008	p1	09.00	10.30
					p2	22.00	23.00

Fig. 5. Result of tolerant natural join operations applied on tables RPLPA and WPPA

R3. Contextual formulation of request

For all standard routes which are planned for all flight crews (CFC) determine time of their flight trough cross (contact) points of routes with PAs (TC_RP). The result should be presented by the table "Times of flight of aircraft through the limit points of PAs"

TFRPLPA (DATE_F, NUM_STR, CFC, NUM_RP, TC_RP).

Formal notation of request in a form of algebraic expression

TFRPLPA = $\pi_{\text{DATE\_F, NUM\_STR, CFC, NUM\_RP, TF\_RP}}$ (**OFRP**)[NUM_STR, NUM_RP, TC_RP)]**RPLPA**)

prescribes producing of projection operation (π) on attribute DATE_F, NUM_STR, CFC, NUM_RP, TC_RP of natural join of rows of table **OFRP** and **RPLPA** based on combination of values of their equally named attributes (NUM_STR, NUM_RP).

Having done these operations database management system will form prescribed by the algebraic formula table **TFRPLPA** (figure 6).

R4. Contextual formulation of request

For all standard routes which are planned for all flight crews (CFC) determine values of conflict indicator (CI) in the crossing (connect) points of routes with the limits of PAs. The result should be presented by the table "Potential conflict situations"

PCS (DATE_F, NUM_STR, CFC, NUM_RP, TC_RP).

Formal notation of request in a form of algebraic expression

PCS = $\pi_{\text{DATE\_F, NUM\_STR, CFC, NUM\_RP, TYPE\_RP, TF\_RP, NUM\_PC, TB\_C, TE\_C}}$(**TFRPLPA** [DATE_F = DATE_C, NUM_STR, NUM_RP)] **PCRPLPA**)

prescribes producing of projection operation (π) of rows of table **TFRPLPA** and **PCRPLPA** on attributes DATE_F, NUM_STR, CFC, NUM_RP, TYPE_RP, TF_RP, NUM_PC, TB_C based on combination of values of their equally named attributes (NUM_STR, NUM_RP) and differently named attributes DATE_F, DATE_C but having common domain "DATE".

TFRPLPA: TIME OF FLIGHT THROUGH POINTS OF LIMITS OF PROHIBITED AREAS

DATE_F	NUM_STR	CCS	NUM_RP	TF_RP
20.09.2008	STR003	CK50	p4	09.25
			p5	09.37
		C37	p4	18.10
			p5	18.22
	STR005	C07	p3	10.56
			p4	11.08
		C15	p3	18.51
			p4	19.03
	STR001	C99	p2	10.15
		C77	p2	12.20

Fig. 6. Result of projection of natural join of tables RPLPA and OFRP based on combination of values of attributes (NUM_STR, NUM_RP)

Having done these operations database management system will form prescribed by the algebraic formula table **TFRPLPA** (figure 7).

PCS: POTENTIAL CONFLICT SITUATIONS

DATE_F	NUM_STR	CCS	NUM_RP	TYPE_RP	TF_RP	NUM_PC	TB_C	TE_C	CI
20.09.2008	STR003	**C50**	p4	ent_a2	09.25	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
			p5	**ext_a2**	**09.37**	**wp1**	**09.30**	**10.30**	**1**
						wp2	19.00	20.00	0
		C37	p4	ent_a2	18.10	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
			p5	ext_a2	18.22	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
	STR005	C07	p3	ent_a4	10.56	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
			p4	ext_a4	11.08	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
		C15	**p3**	**ent_a4**	**18.51**	wp1	08.00	09.00	0
						wp2	**18.00**	**19.00**	**1**
			p4	**ext_a4**	**19.03**	wp1	08.00	09.00	0
						wp2	**18.00**	**19.00**	**1**
	STR001	**C99**	**p2**	**a5**	**10.15**	**wp1**	**09.00**	**10.30**	**1**
						wp2	22.00	23.00	0
		C77	p2	a5	12.20	wp1	09.00	10.30	0
						wp2	22.00	23.00	0

Fig. 7. Result of natural join projection of tables TFRPLPA and PCRPLPA based on combination of values of attributes (DATE_F = DATE_C, NUM_STR, NUM_RP) and determination of CI value

Value of attribute CI in this table is determined with the help of examined previously equation (1) and (2) taking into account that t_{ent} and t_{ext} are determined by combination of values of attributes TB_C and TE_C accordingly.

5. Avoidance of PCS in a flight plan

Analysis of data presented in the table PCS (figure 7) created by means of sequence of request R1 – R4 lets show truth of assertion about existence of PCS which are implicit in produced variant of PFP. We shall explain this case by example for flight crew with call name C50:

1. as far as concern of time of entrance (TC_RP = 09.25) into a prohibited area a2 (crossing of route point p4) this flight doesn't conflict with any working periods of this area (therefore CI = 0);
2. as far as concern of time of exit (TC_RP = 09.37) from a PA a2 (crossing of route point p5) one can see that this flight will be evidently fulfilled during time of the first working period (p1) of this area (therefore CI = 1).

Thus, for given flight the condition (2) is true. This fact is indicated in flight plan by bold type of relevant data in tables **FSTR** and **FRP** as shown on figure 7.

Taking into consideration that time of crossing of the PA equals 12 minutes ($t_{ext} - t_{ent}$ = 09.37 –°09.05 = 00.12) for a purpose of avoidance of PCS it is necessary to preplan more early departure, at least on 8 minutes (in this case given flight will cross PA a2 before beginning of its working period p1: (t_{ent} = 09.17, t_{ext} = 09.29), or preplan more late departure, with delay time at least 1 hour 6 minutes (then given flight will cross the prohibited area a2 after ending of its working period p1: (t_{ent} = 10.36, t_{ext} = 10.48).

A flight planner may accomplish these or analog derivations basing on direct analysis of table **PCS** content (or from any other source, reflecting the essence of situation characterized by data from this table), or with help of relevant software, which is capable not only to calculate any flight plans and to detect existence of PCS with the PAs, but also to form most appropriate recommendations for their avoidance.

Let us suppose, that analysis of other PCS, existing in examined flight plan and producing of decision on their avoidance were executed by a similar method as in example for flight crew with call name CFC = C50. A flight planner had used only departure time acceleration/delay technique to avoid detected PCSs: departure time of flight crew with call name CFC = C15 on route STR005 he had delayed on 10 minutes and departure time of flight crew with call name CFC = C99 on route STR001 — on 10 minutes. These decisions were actuated by inserting a new planned departure time (TIME_DPT) into database table **FSTR** and by recalculating of crossing times values for every route points (figure 8).

Accomplishing of sequence of procedures (requests R1—R4) described previously for processing of changed instance of examined DBS tables proves an absence of PCS in changed flight plan (figure 9).

6. Conclusions

Thus contemporary databases technologies allow us to resolve the tasks of PCS avoidance during PFP process by means of natural join projection operation. A whole class of PFP tasks may be similarly resolved.

FSTR: FLIGHT ON STANDARD ROUTES

DATE_F	NUM_STR	CCS	TM_DEP	TM_ARV	TYP_AP
20.09.2008	STR005	C07	10.05	11.25	Yak-40
	STR005	C15	**18.10**	**19.30**	Yak-40
	STR001	C99	**10.01**	**11.01**	Tu-154
	STR001	C77	11.50	12.50	Tu-154
	STR003	C50	**07.13**	**11.13**	An-12
	STR003	C37	15.30	19.30	An-12

FRP: FLIGHT THROUGH ROUTE POINTS

DATE_F	NUM_STR	CCS	NUM_RP	TF_RP	H_F	TS_F
20.09.2008	STR007	C07	p3	10.56	7000	600
			p4	11.08	7000	600
		C15	p3	**19.01**	7000	600
			p4	**19.13**	7000	600
	STR003	C50	p4	**09.13**	6000	500
			p5	**09.25**	6000	500
		C37	p4	18.10	6000	500
			p5	18.22	6000	500
	STR001	C99	p2	**10.31**	9000	850
		C77	p2	12.20	9000	850

Fig. 8. An instance of database tables after changing of its TIME_DPT attribute values

PCS: POTENCIAL CONFLICT SITUATIONS

DATE_F	NUM_STR	CCS	NUM_RP	TYPE_RP	TF_RP	NUM_PC	TB_C	TE_C	CI
20.09.2008	STR003	C50	p4	ent_a2	09.13	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
			p5	ext_a2	**09.25**	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
		C37	p4	ent_a2	18.10	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
			p5	ext_a2	18.22	wp1	09.30	10.30	0
						wp2	19.00	20.00	0
	STR005	C07	p3	ent_a4	10.56	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
			p4	ext_a4	11.08	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
		C15	p3	ent_a4	**19.01**	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
			p4	ext_a4	**19.13**	wp1	08.00	09.00	0
						wp2	18.00	19.00	0
	STR001	C99	p2	a5	**10.31**	wp1	09.00	10.30	0
						wp2	22.00	23.00	0
		C77	p2	a5	12.20	wp1	09.00	10.30	0
						wp2	22.00	23.00	0

Fig. 9. Result of processing applied to changed DBS tables

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