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Design of passenger airplanes with taking into account their operation within the fleet

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Design stages flowchart. Place of Pre-Design stage within the aircraft design process

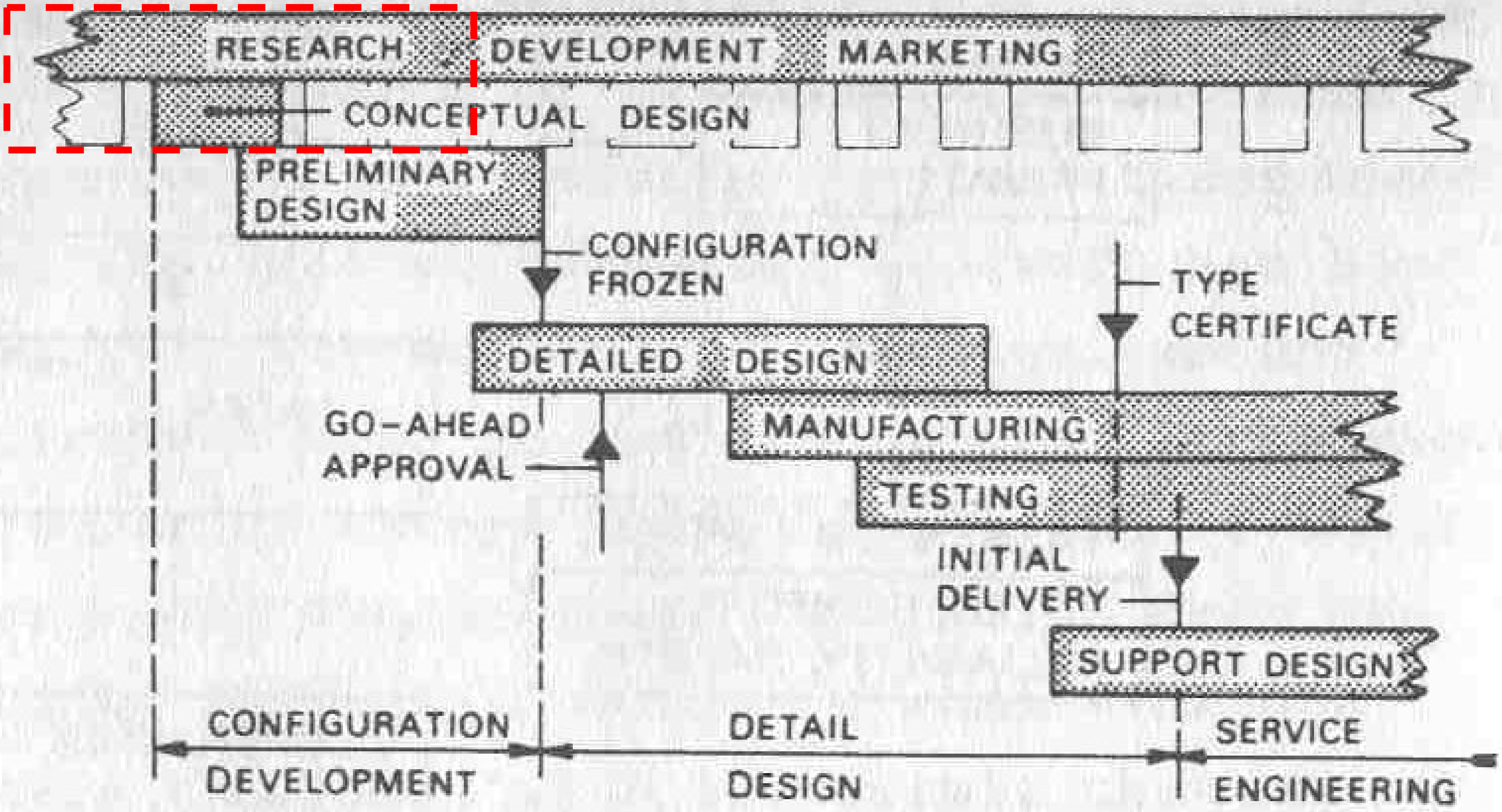

Fig. 1-2. Airplane design and development

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Design stages flowchart. Place of Pre-Design stage within the aircraft design process

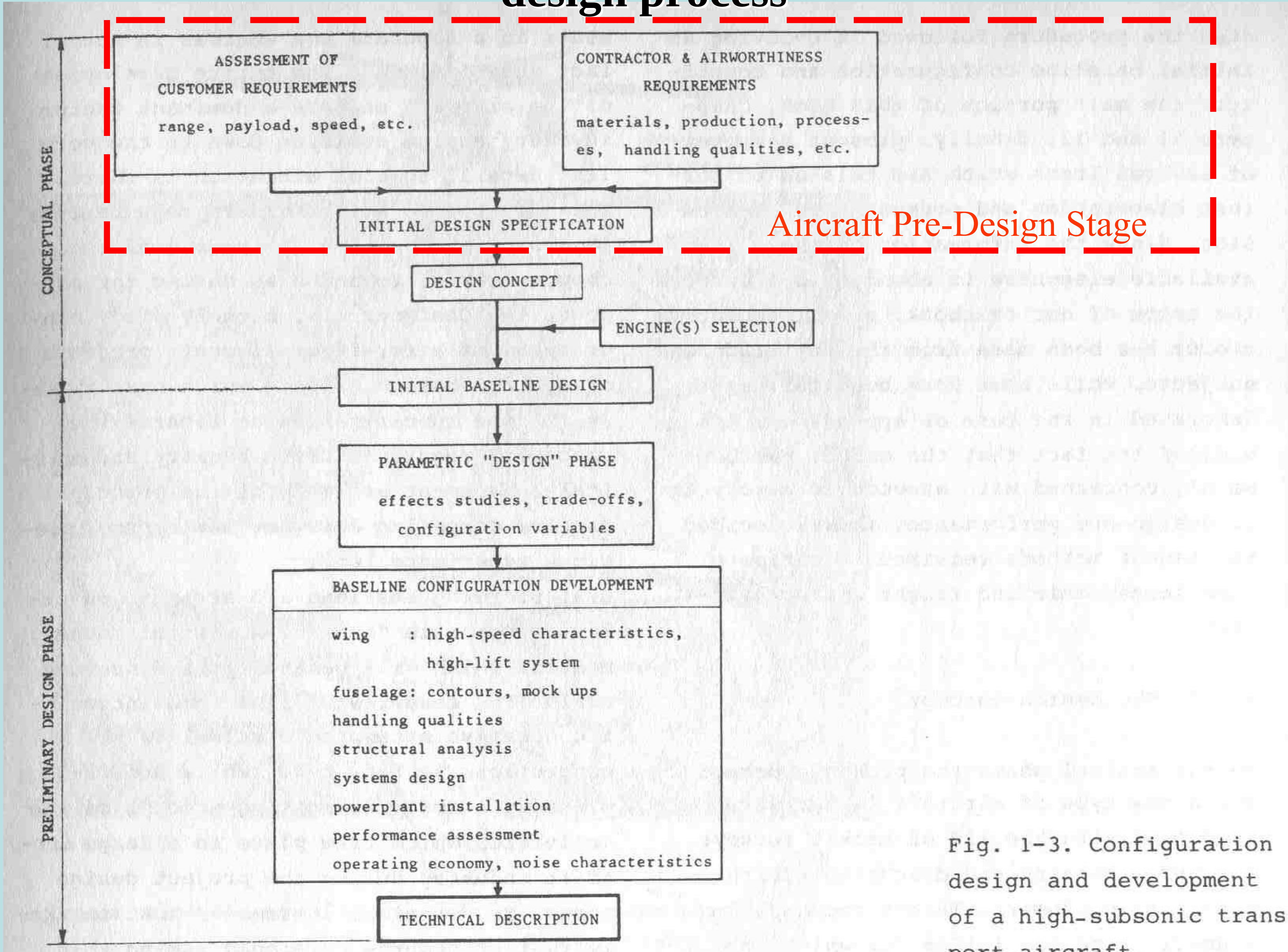

Fig. 1-3. Configuration design and development of a high-subsonic transport aircraft.

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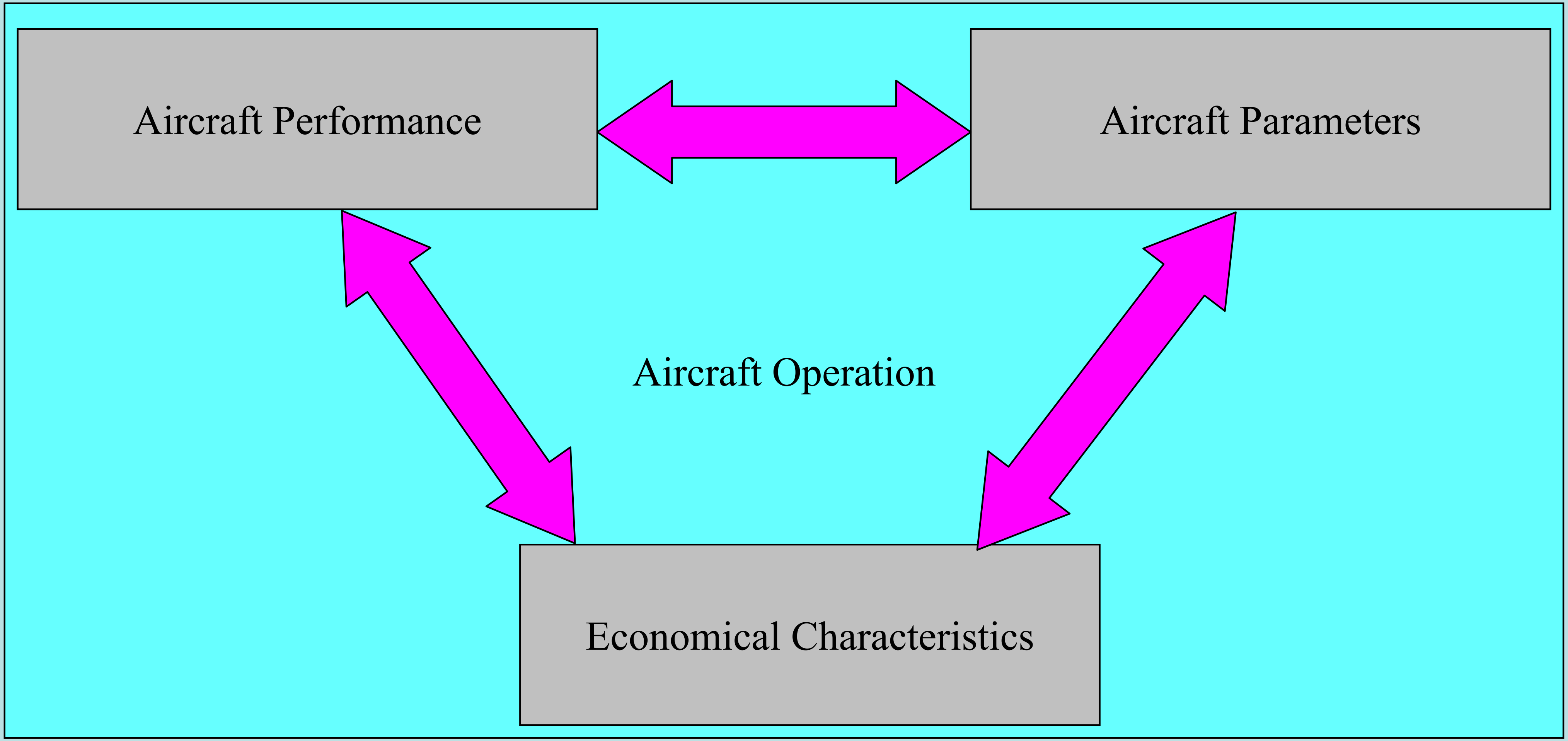
First stage of Aircraft Design (Concept(ual) Design)



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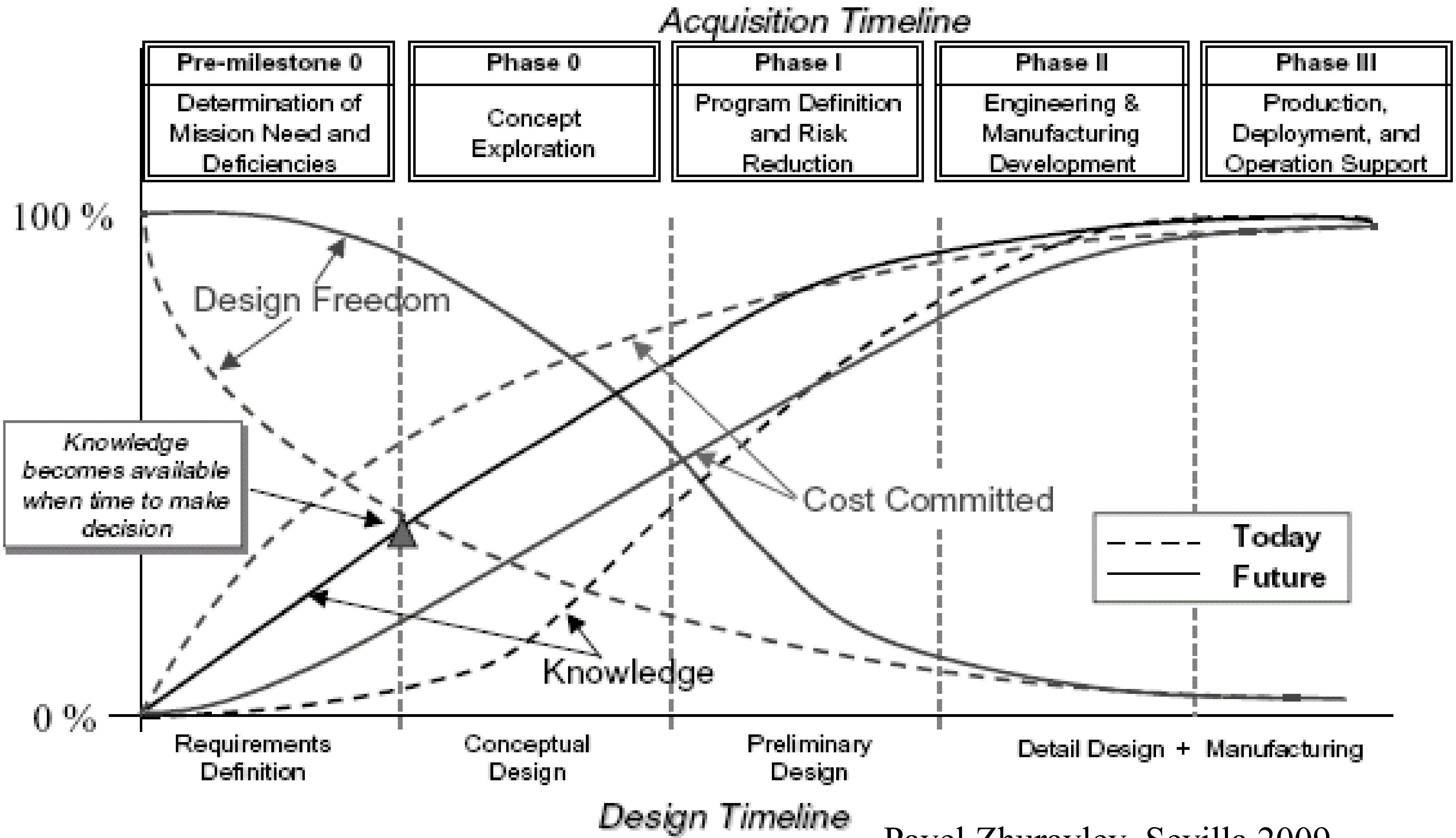
Necessity of taking into the account the operation of aircraft during its design

Main reasons for taking into account operation during design of aircraft:

- Design stage is the stage with relatively low investments and a lot of decisions to be made;
- Each aircraft produced requires a lot of technical and technological innovations, many of which are to be invented and introduced into operation;
- The process of developing a new aircraft takes more and more time over the years passing. Therefore the mistakes made can have dramatically affect the company, the operator and the industry as a whole.

The Relationship between Design Freedom, Knowledge & Cost Committed



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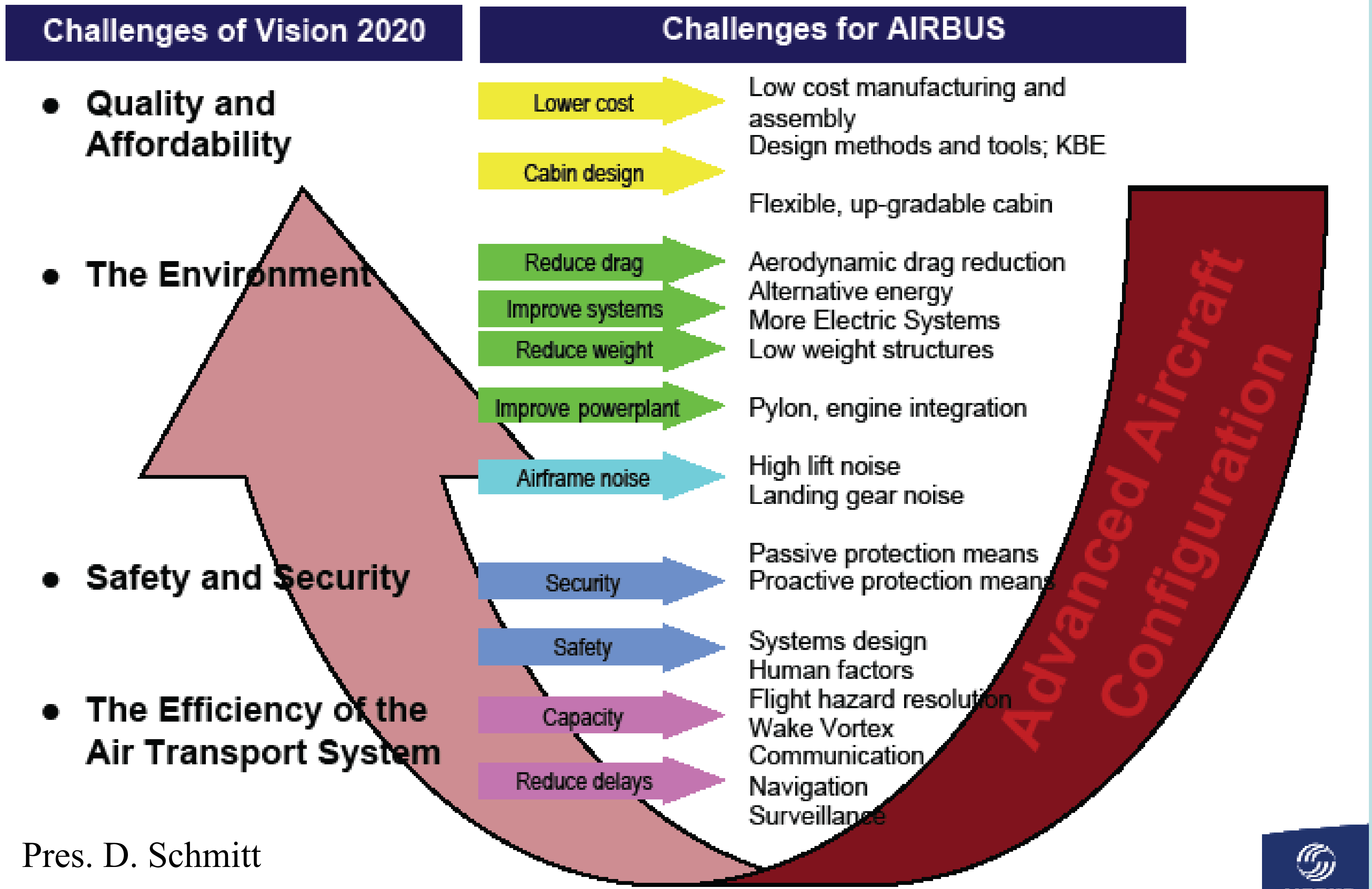
How will Airbus implement the vision?



Pres. D. Schmitt

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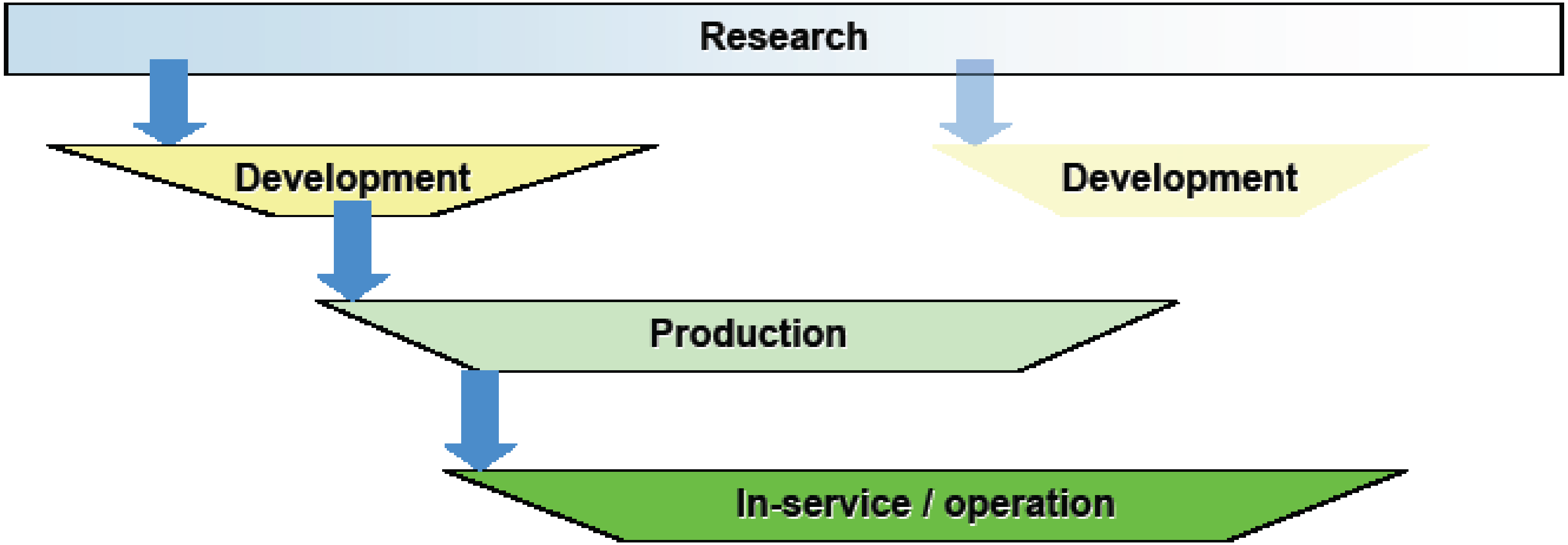
~5-10 ~5 20-40 years 25 years

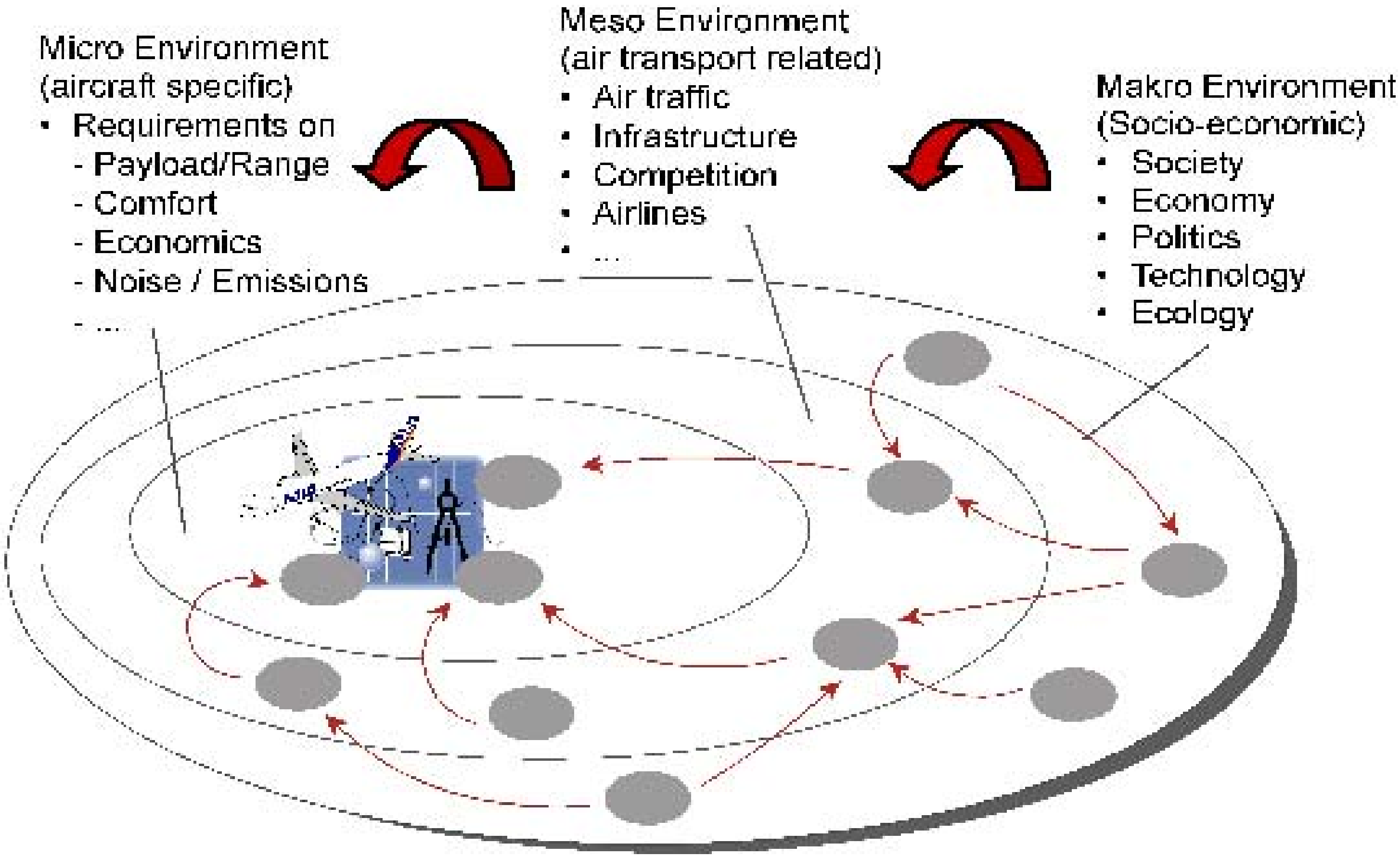


Aeronautics has a long term cycle

Pres. D. Schmitt

Due to the big importance of the Pre-Design stage during the creation of a new aircraft it is necessary to carry out the first stages of design (up to detailed design) basing on the analysis of the results of the future operation of the created aircraft.

Rationalise future challenges



Modelling of the world context will provide insight and rationale to prioritise the different concepts for the benefit of the end customer as well as for the aircraft manufacturer

AIRBUS

Pres. D. Schmitt EWADE 2005

Aircraft Design is a decision-making process, which involves optimization

- The process of Aircraft Design consists in making sequential design decisions
- The process of making each decision can be formally described as the process of solving an optimization problem
- The general formulation of an optimization problem during aircraft design (design of Complex Aviation Systems (CAS)) is shown on the next slide

General definition of a problem of optimization of aircraft operation

$$W_S\left(\overline{a},\tau_K\right)=\int\limits_{z_1\in Z_1}\sup_{\overline{b}\in B}\inf_{\substack{g\in G\\ d\in D\\ z_2\in Z_2}}\left[\int\limits_{z_3\in Z_3}\inf_{z_4\in Z_4} W_S\left(\overline{a},\overline{b},\overline{d},\overline{g},z,\tau_K\right)dF\left(z_3\right)\right]dF\left(z_1\right)$$

$\overline{a}$ is the multitude of performance and parameters of the designed aircraft (possessed by the operating party)

$\overline{b}$ is the multitude of tactical decisions for the designed (considered) aircraft

$\overline{d}$ is the multitude of performance and parameters of the competitors' aircraft

$\overline{g}$ is the multitude of strategies of the competitor

$\boldsymbol{S}$ is the task which should be carried out

τ_K is the forecasted moment (year) of start of the operation (start of planning period)

$\boldsymbol{z}$ is the multitude of uncertain factors, which influence the operation.

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General definition of a problem of optimization of aircraft operation

$$W_S\left(\bar{a},\tau_K\right)=\int\limits_{z_1\in Z_1}\sup_{\bar{b}\in B}\inf_{\substack{g\in G\\ d\in D\\ z_2\in Z_2}}\left[\int\limits_{z_3\in Z_3}\inf_{z_4\in Z_4}W_S\left(\bar{a},\bar{b},\bar{d},\bar{g},z,\tau_K\right)dF\left(z_3\right)\right]dF\left(z_1\right)$$

z is the multitude of uncertain factors, which influence the operation. This multitude can be subdivided into:

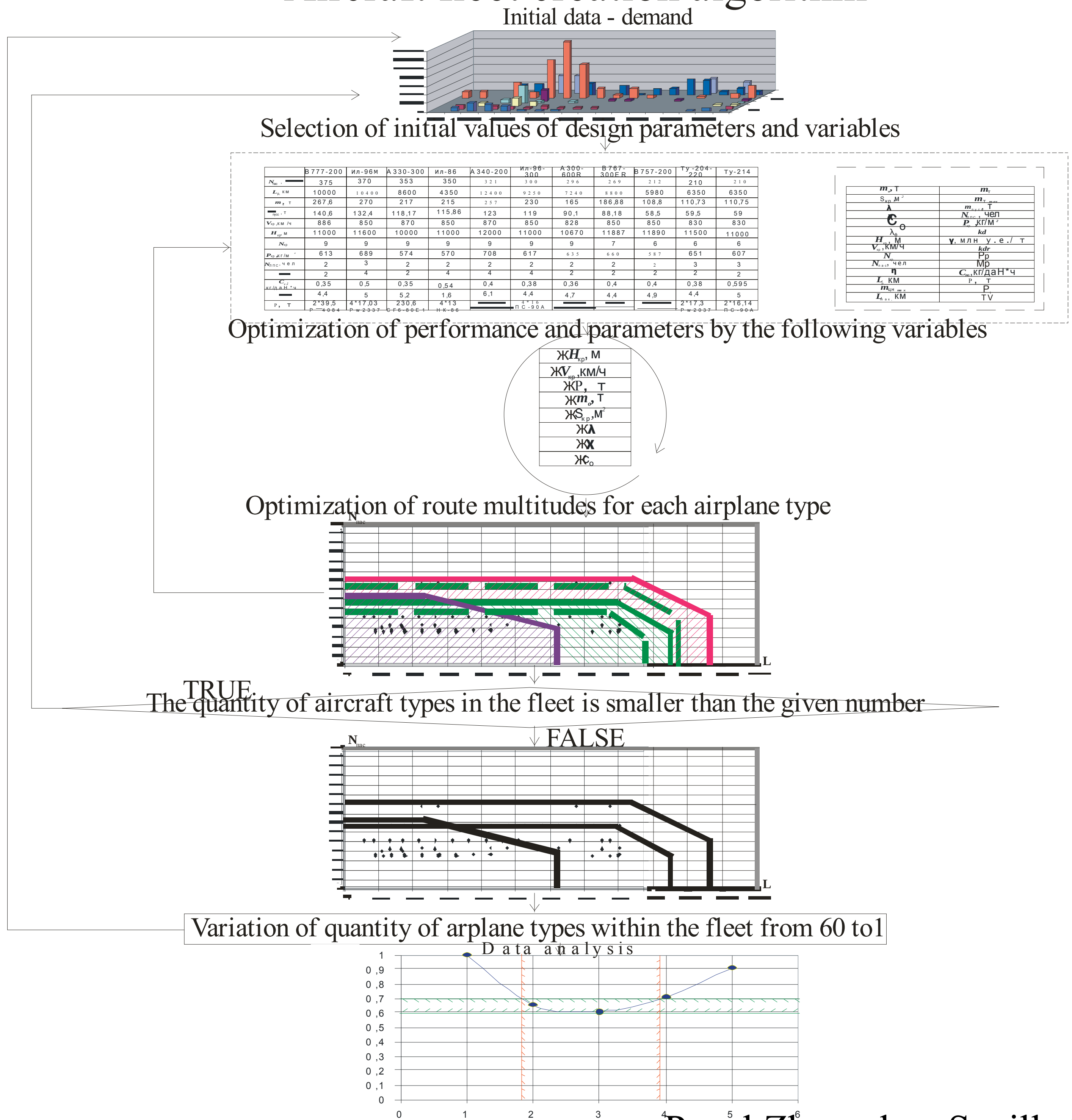
$\boldsymbol{z_1}$ is the multitude of the uncertain factors (conditions), concerning which there is information only about the range of their values

$\boldsymbol{z_2}$ is the multitude of the uncertain factors (conditions), concerning which there is information about the distribution law of their values $F(z_2)$

$\boldsymbol{z_3}$ is the multitude of the uncertain factors (conditions), concerning which there is information both about the range of their values and the particular values before carrying out the operation

$\boldsymbol{z_4}$ is the multitude of the uncertain factors, concerning which there is information both about the distribution law of their values and the particular values before carrying out the operation;

Aircraft fleet creation algorithm



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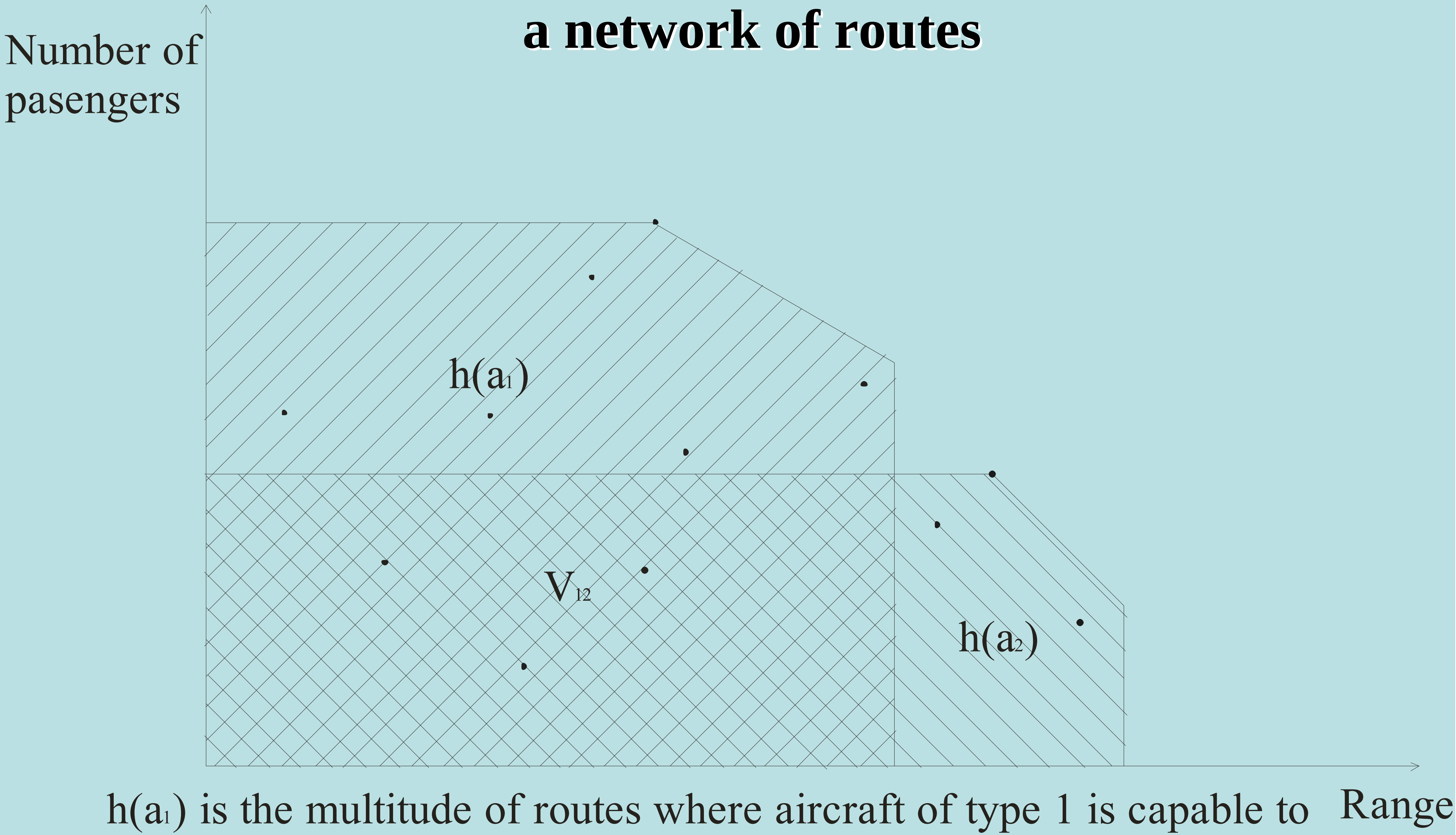
Modeling of operation of various types of aircraft on a network of routes



$h(a_1)$ is the multitude of routes where aircraft of type 1 is capable to carry out passenger air transportation

$h(a_2)$ is the multitude of routes where aircraft of type 2 is capable to carry out passenger air transportation

V_{12} is the competition area

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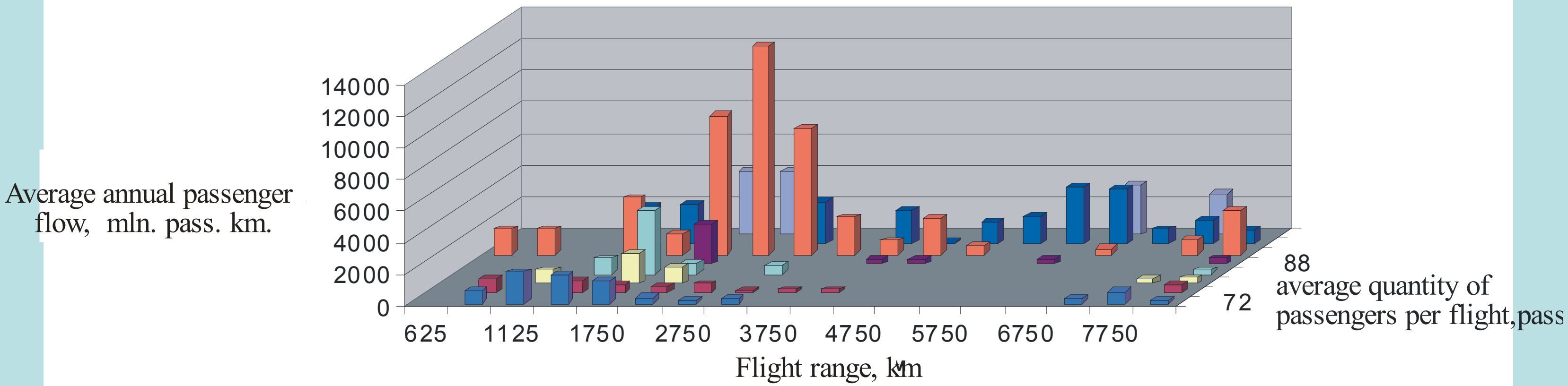
Initial data

Dependency of passenger flow (mln . pass km)depending on range of air passenger transportation and average quantity of passengers per flight

	Range of passenger air transportation ,km																			
	0-250	250-500	500-750	750-1000	1000-1250	1250-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500	5500-6000	6000-6500	6500-7000	7000-7500	7500-8000	more than 8000
0-6	41	119	134																	
6-10	24	24	273	131																
10-14		41	139	319	115															
14-18		27	114	96	458	583														
18-22		33	65		110	174	1339													
22-26			105	152	91	216	716	1230												
26-30		50	132	282		202	282	897	1150											
30-34		39	36	76		47	154	58	1186	898										
34-38		64	47	136	50		118	137	156	1298	461									
38-42			171	129	53	121	390	220	83		946	342								
42-46			207	82	64		292	422	196	317	114	838	220							
46-50			454	225	222	77	81			231		137	901	257						
50-54			422	205	83	84	180	365	332	249				552	180					
54-58				192	718	108	309	104	117		152				419	427				
58-62				476	575		455			147					196	248	400			
62-66					1003	588	355	463		304	163						755	273		
66-70					290	842	1413	403	427									401	517	
70-74				810	1970	1751	1368	359	174	335								273	744	188
74-78				910		722	537	404	609	198	207	209								518
78-82					862		1916	998											300	331
82-86						1003	3995	649		529										268
86-90								2519				287	292			316				380
90-120			1580	1600		3604	1318	8798	13172	7972	2316	842	2257	579			384		910	2800
120-150						2356	2564			2709		2167	125	1412	1744	3674	3509	954	1575	918
150-200								4044	4056								3151		2601	

Dependency of passenger flow (mln . pass km)depending on range of air passenger transportation and average quantity of passengers per flight



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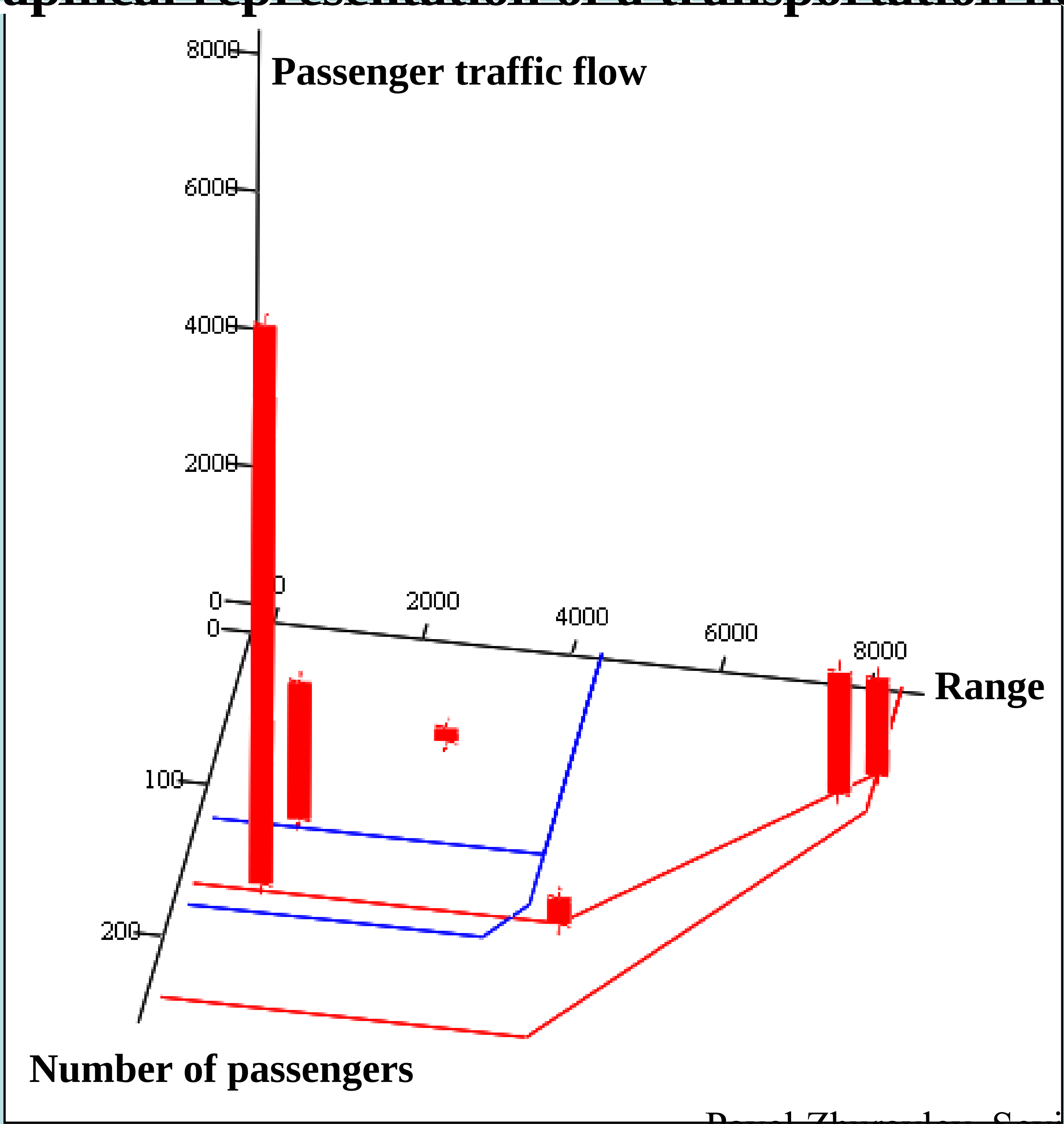
3D Graphical representation of a transportation network



Groups of tasks, which should be solved to model the operation of aircraft

Operation of a single aircraft on a single route (includes selecting the best type of aircraft)

Operation of a single aircraft type on a multitude of routes

Problems concerned with operation of a single aircraft type

Operation of an aircraft fleet on a network of routes (transportation network) during a short given period of time (e.g. one year) (static problem of aircraft fleet creation and optimization)

Operation of an aircraft fleet on a network of routes (transportation network) during a long period of time. Consideration of a number of time-slices on the global time-scale (quasi-dynamic problem of aircraft fleet creation and optimization)

Operation of an aircraft fleet on a network of routes (transportation network) during a long period of time (dynamic problem of aircraft fleet creation and optimization)

Problems concerned with optimization of aircraft fleet operation

General Problem Definition and Breakdown

Creation of a rational fleet of passenger airliners

Optimization of air route multitudes for each type
(N_{pass}^{max}, L_d) and quantity of types in the fleet ***(m)***

Criterion:

Total expenses for fleet operation

$$W_S = F(S,a) = \sum_i H_i(S_i, a_i)$$

Optimization of airplane parameters and performance
and organization of airplane operation

(required quantity of airplanes of one type)

Criterion:

Total expenses on transportation on the multitude of the routes served by the regarded airplane

$$W_S = H_i = \sum_{a \in D_i} f(S_n, a_i)$$

Optimization of allocation of airplane types on the regarded routes

(creation of route multitudes ***D_i***)

Criterion:

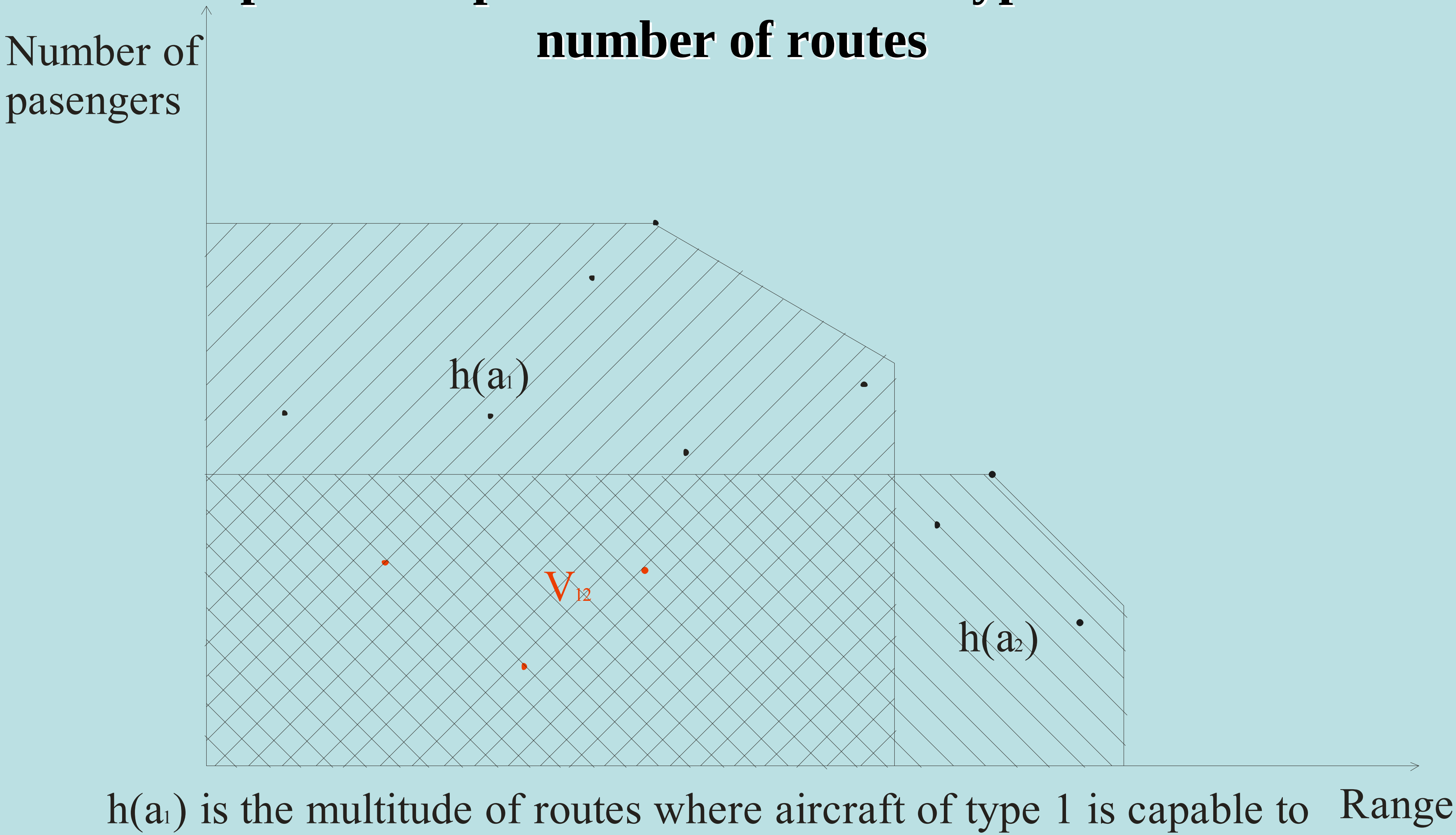
Expenses on one flight

$$w_s = f(S_n, a_i)$$

Aircraft is a part of a complex system

If we consider the process of aircraft operation thoroughly it is easy to see that actually an aircraft functions within the framework of a big system (aircraft fleet). Being a part of this system the aircraft fulfills a number of its missions and interacts with other elements of the big system. Therefore if we are to create a model of aircraft operation it is essential to regard its performance as a part of a complex aviation system (CAS) – aircraft fleet.

An example of competition between two types of aircraft on a number of routes



$h(a_1)$ is the multitude of routes where aircraft of type 1 is capable to carry out passenger air transportation

$h(a_2)$ is the multitude of routes where aircraft of type 2 is capable to carry out passenger air transportation

V_{12} is the competition area

The red dots mark the routes where type 1 competes with type 2 for carrying out passenger transportation.

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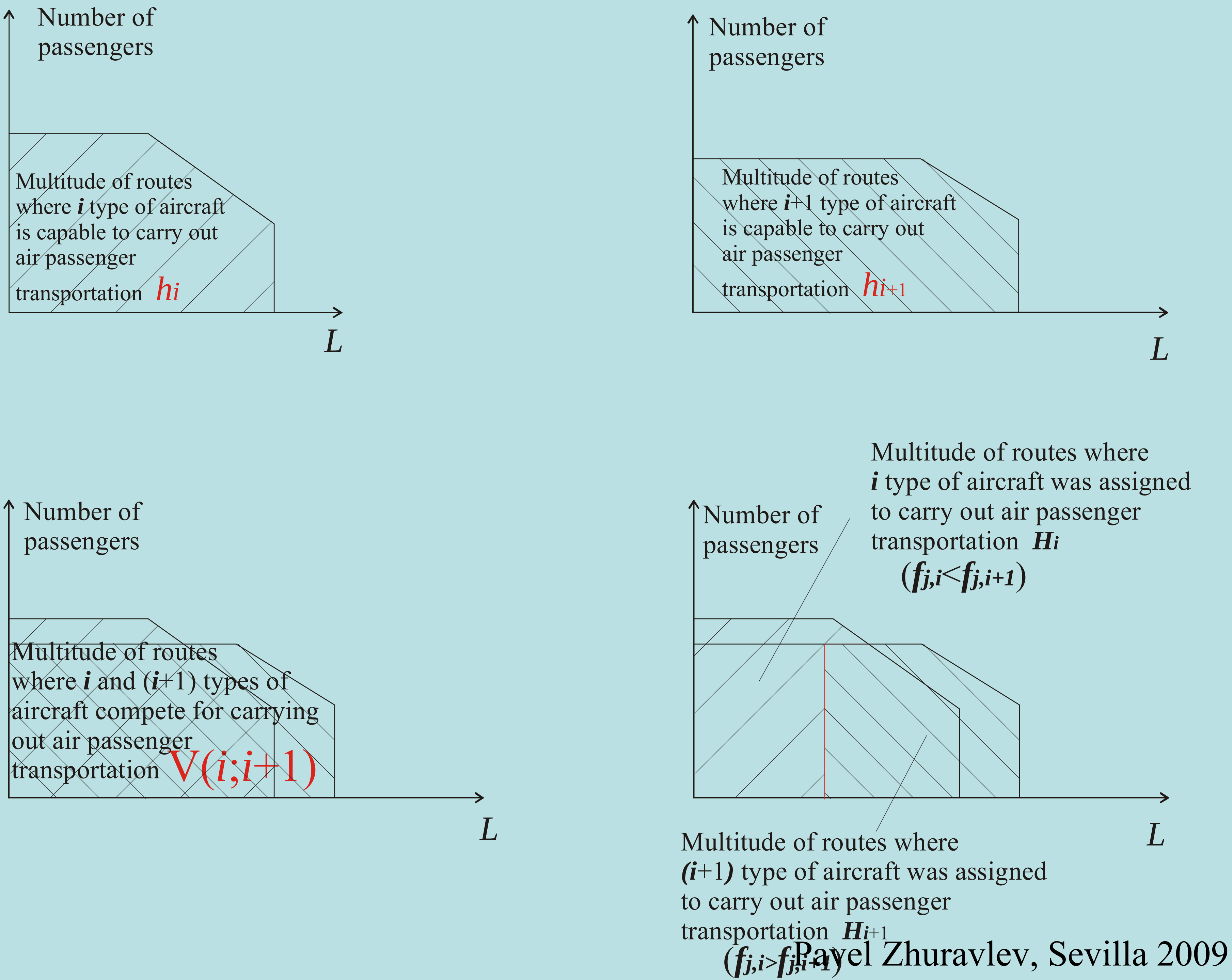
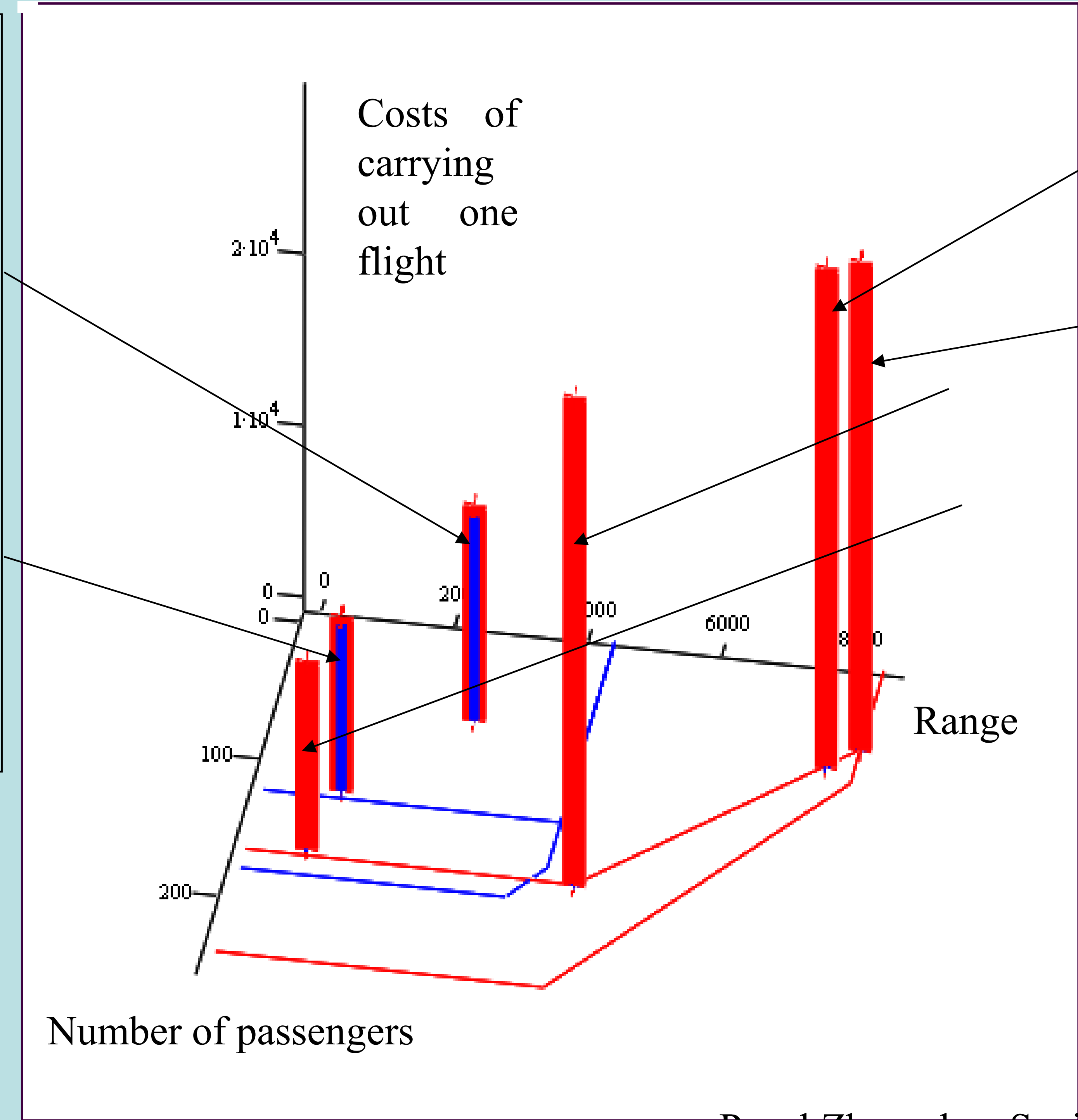
Assignment of airplanes of *i* and (*i*+1) type within a network of routes



Comparison of various aircraft type operation on the network

The blue bars indicate the routes where type 2 is capable to carry out passenger air transportation. The height of the bar represents the costs of carrying out one flight on a route.



The red bars indicate the routes where type 1 is capable to carry out passenger air transportation. The height of the bar represents the costs of carrying out one flight on a route.

Problem of optimizing the process of standard operation of an aircraft (carrying out a number of flights on given routes by a given type of aircraft) during a given period

- ***Objective function*** W_S: the total costs of carrying the passengers (***f***)
- ***Initial data***: the quantity of passengers, which should be carried on the considered line during one flight, range of flight and the passenger flow during a given period of time (starting from τ_K), aircraft characteristics and parameters $\bar{a}$
- ***Variable***: the (number of) type which is assigned to carry out passenger transportation on the route
- ***Main limitation***: the necessity to carry out all air passenger transportation (the passenger flow, which would in fact be transported on a route, should exceed or be equal to the demand) (true for all tasks)

Problem of optimizing the process of standard operation of an aircraft. Creating specialization areas.

The comparison of operation of different aircraft types on the routes is made based on the costs of carrying out a single flight on these routes. As a result every aircraft type is assigned to carry out air transportation on a certain multitude of routes, which is called its "area of specialization".

$$H_i = \left\{ x_j \,/\, f\left(x_j, a_i\right) \le f\left(x_j, a_k\right), \forall k \ne i, x_j \in h\left(a_i\right), x_j \in h\left(a_k\right) \right\}$$

where:

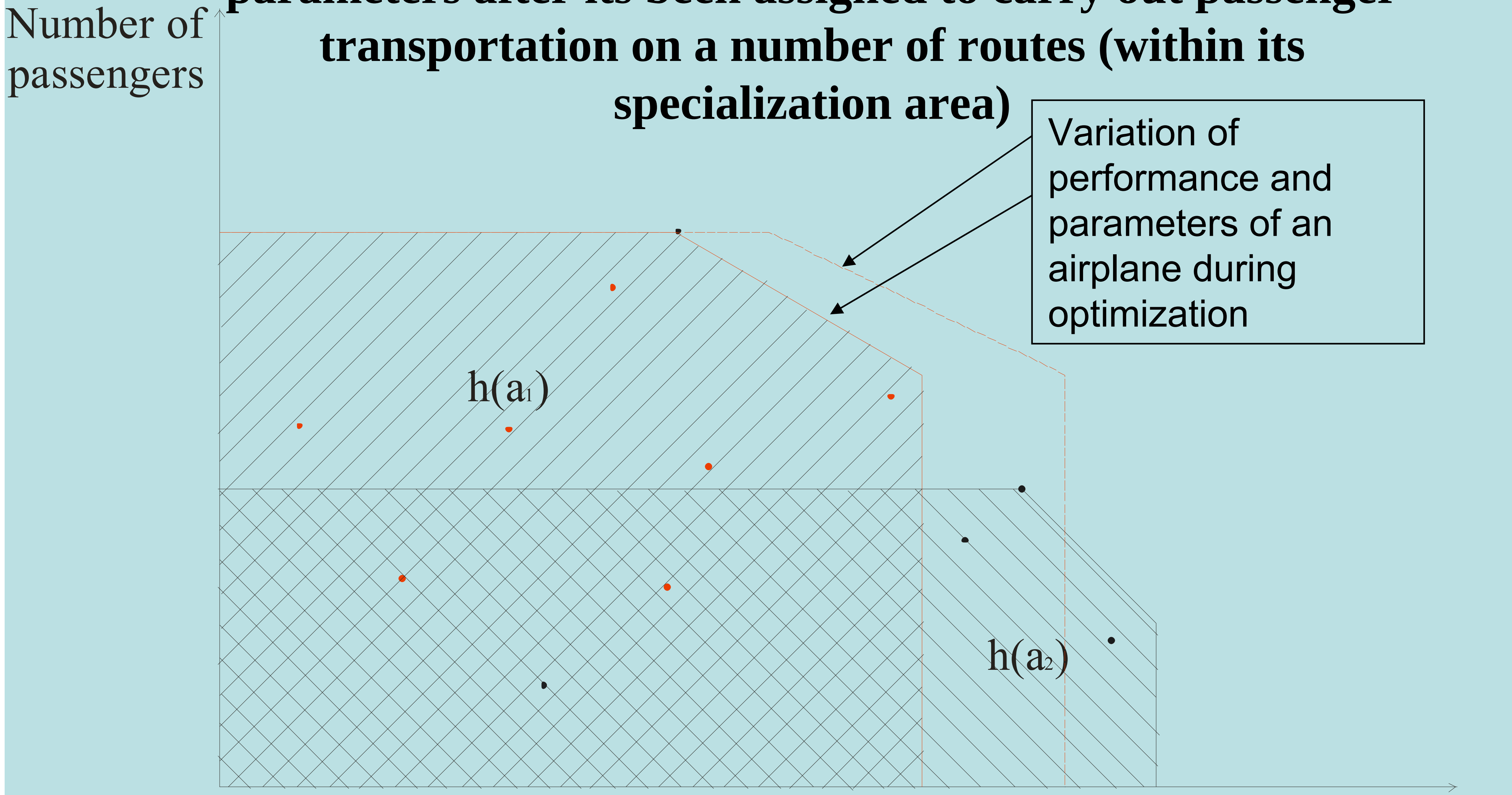
$\boldsymbol{H_i}$ is the specialization area for aircraft type *i*

$\boldsymbol{f(x_j, a_i)}$ are the costs of carrying out one flight on route ***j*** by airplane of type ***i***

$\boldsymbol{x_j}$ are the characteristics of route ***j***

$\boldsymbol{h(a_i)}$ is the multitude of routes where an aircraft of type ***i*** is capable to carry out passenger air transportation

An example of optimization of aircraft performance and parameters after its been assigned to carry out passenger transportation on a number of routes (within its specialization area)



$h(a_1)$ is the multitude of routes where aircraft of type 2 is capable to carry out passenger air transportation

$h(a_2)$ is the multitude of routes where aircraft of type 2 is capable to carry out passenger air transportation

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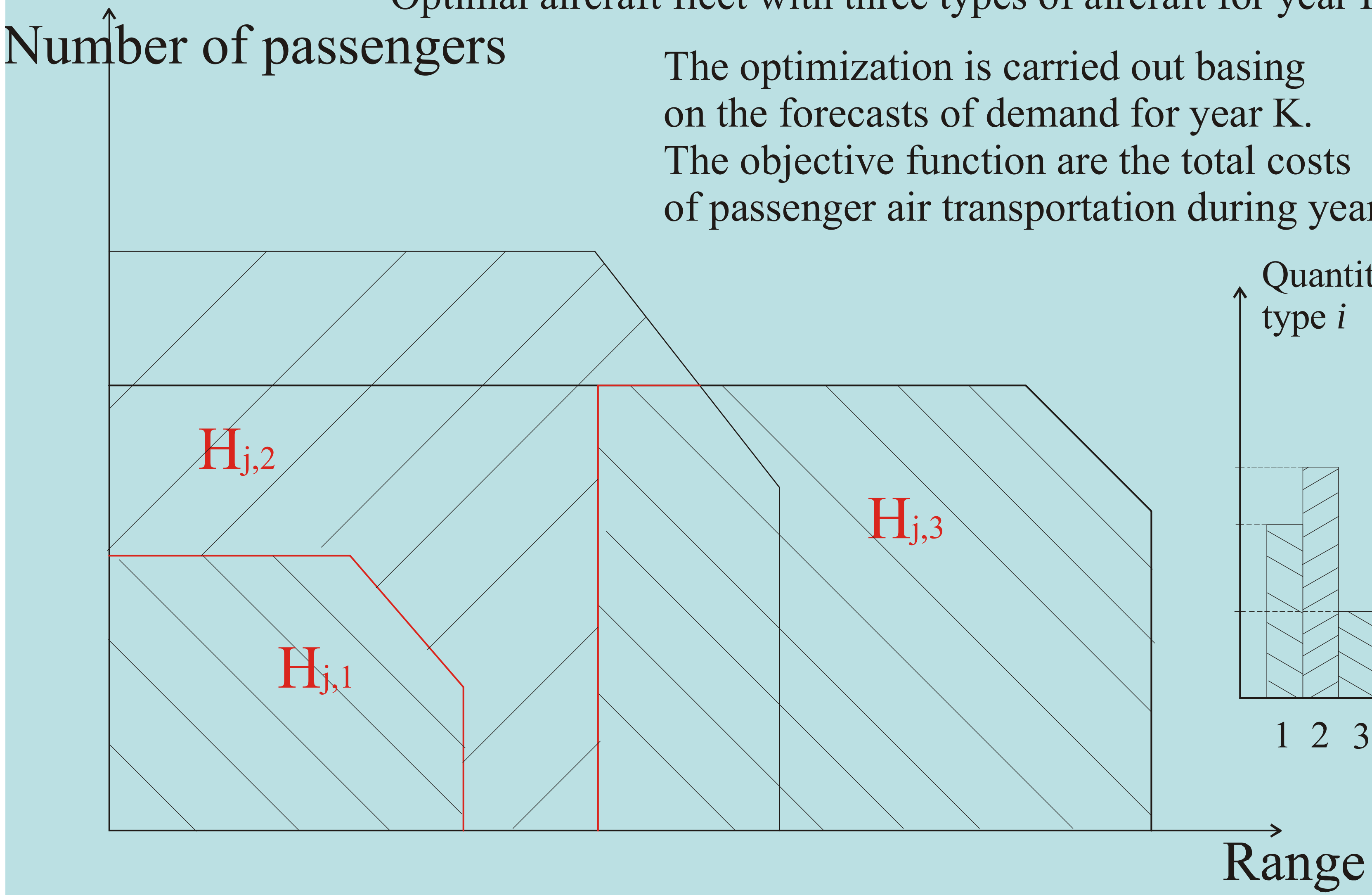
Problem of optimizing the operation of an aircraft on the routes where it has been selected to carry out passenger transportation service

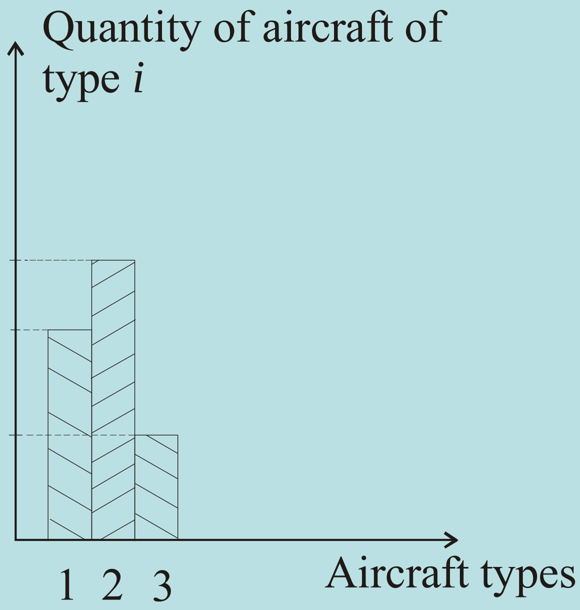
- ***Objective function*** W_S: the total costs of carrying passengers on all routes (where the considered type of airplane was chosen to transport passengers) during the given period of time
- ***Initial data***: performance and characteristics of the optimized aircraft type (including the starting values of its variables) (from the multitude $\overline{a}$) as well as the data describing the routes where it has been selected to carry out air passenger transportation
- ***Variables***: changeable characteristics (parameters and performance) of the airplane (from the multitude $\overline{a}$)
- ***Main limitation***: the necessity to carry out all air passenger transportation

Static problem of aircraft fleet optimization

Optimal aircraft fleet with three types of aircraft for year K

The optimization is carried out basing
on the forecasts of demand for year K.
The objective function are the total costs
of passenger air transportation during year K.





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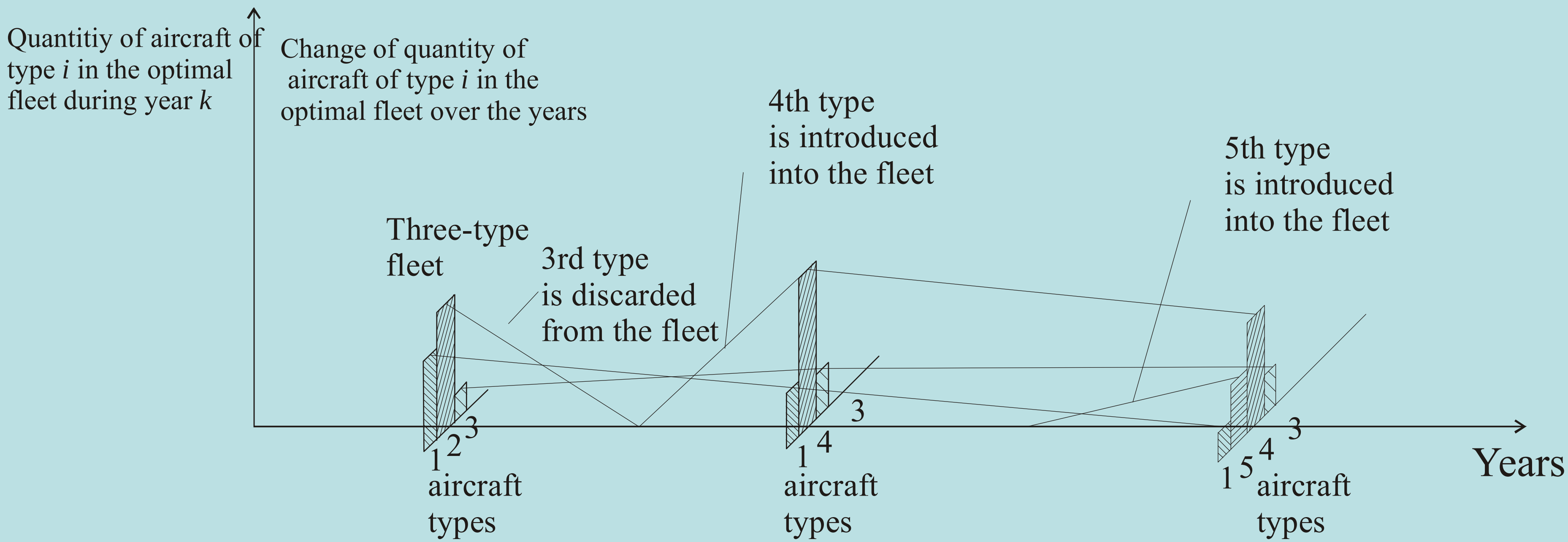
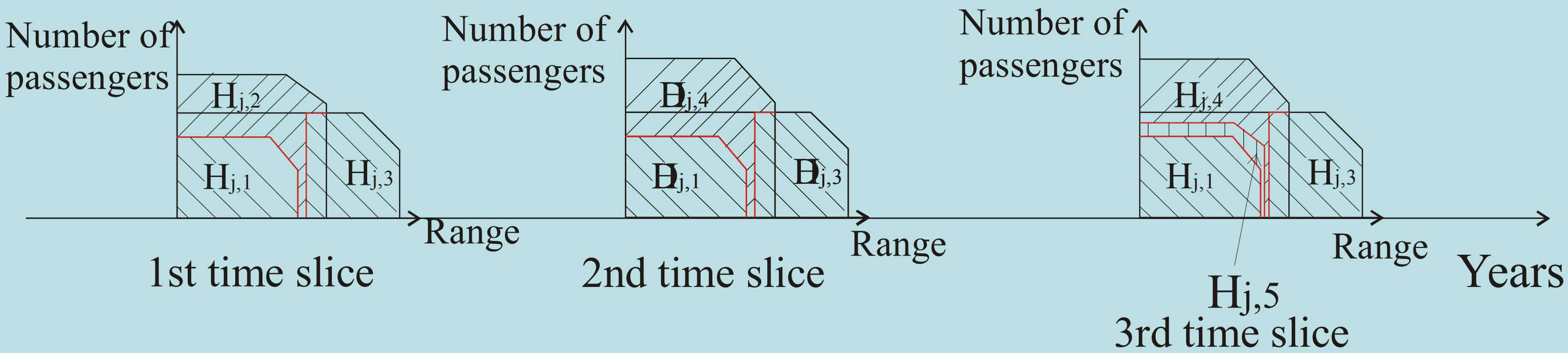
Static problem of aircraft fleet creation and optimization

- ***Objective function*** W_S: total fleet costs for transporting passengers over the considered network within the given period of time (starting from τ_K)
- ***Variable***: the quantity of various types of aircraft
- ***Initial data***: the characteristics of the regarded aircraft $\overline{a}$ and the characteristics of the air routes within the considered transportation network
- ***Main limitation***: the necessity to carry out all air passenger transportation

“Quasi-dynamic” problem of aircraft fleet optimization. For every time slice the objective function are the total costs for carrying out passenger air transportation in the considered time period.





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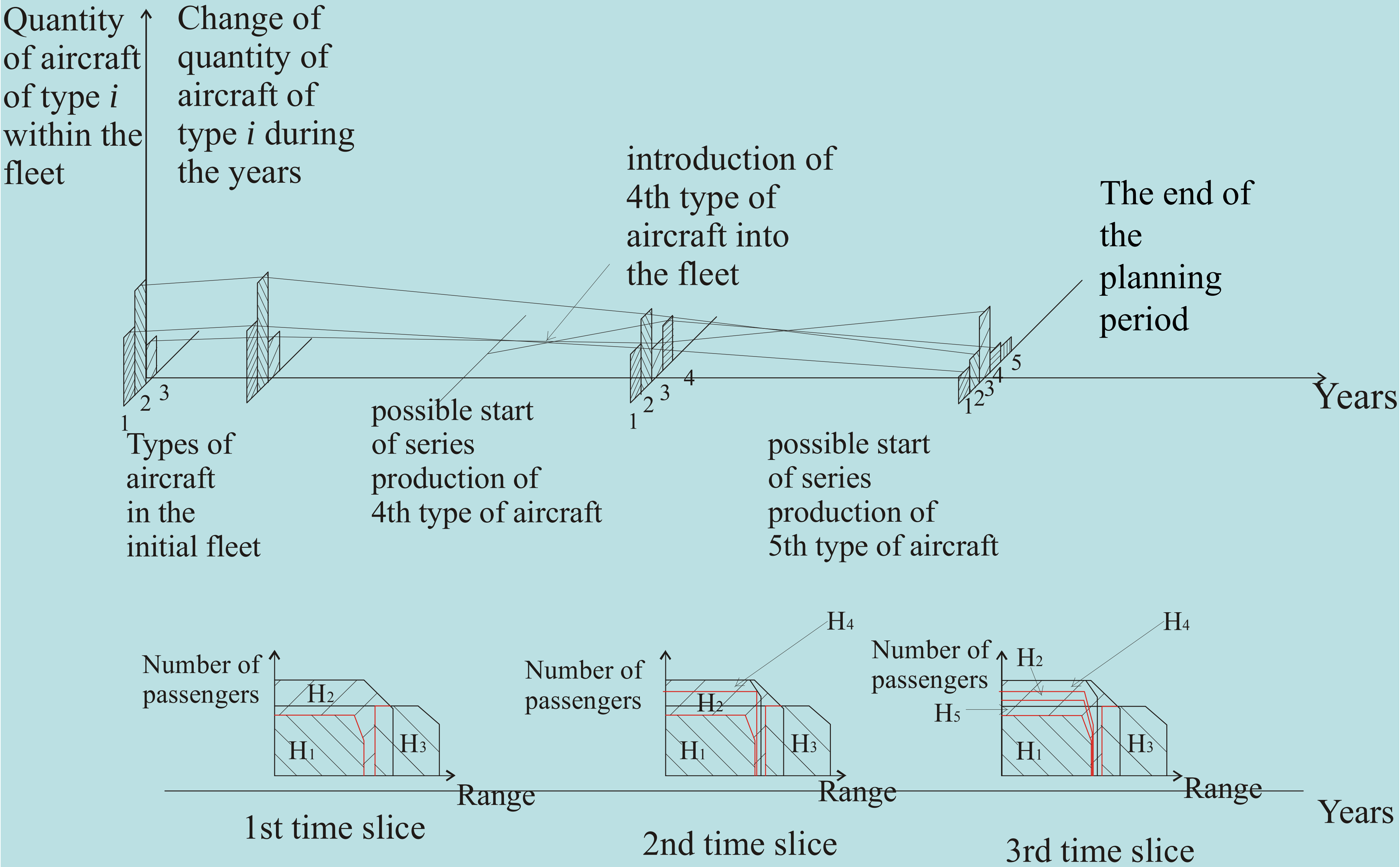
Quasi-Dynamic problem of aircraft fleet creation and optimization.

- network changes with time (the shape and demand on the network change)
- such problem statement does not take into the account the introduction of new types into the fleet and writing-off (retirement) of old types from the fleet
- quasi-dynamic problem of aircraft fleet creation consists in solving a number of static aircraft fleet creation problems, which are solved under various conditions for various years on a global time-scale. The process of solution of each static problem is conducted separately and independently thus resulting in a number of solutions for a number of “time slices” on the regarded global time-scale.
- the objective function W_S in this case is a multitude of objective functions, each of which is calculated separately for each static problem

Dynamic problem of aircraft fleet optimization



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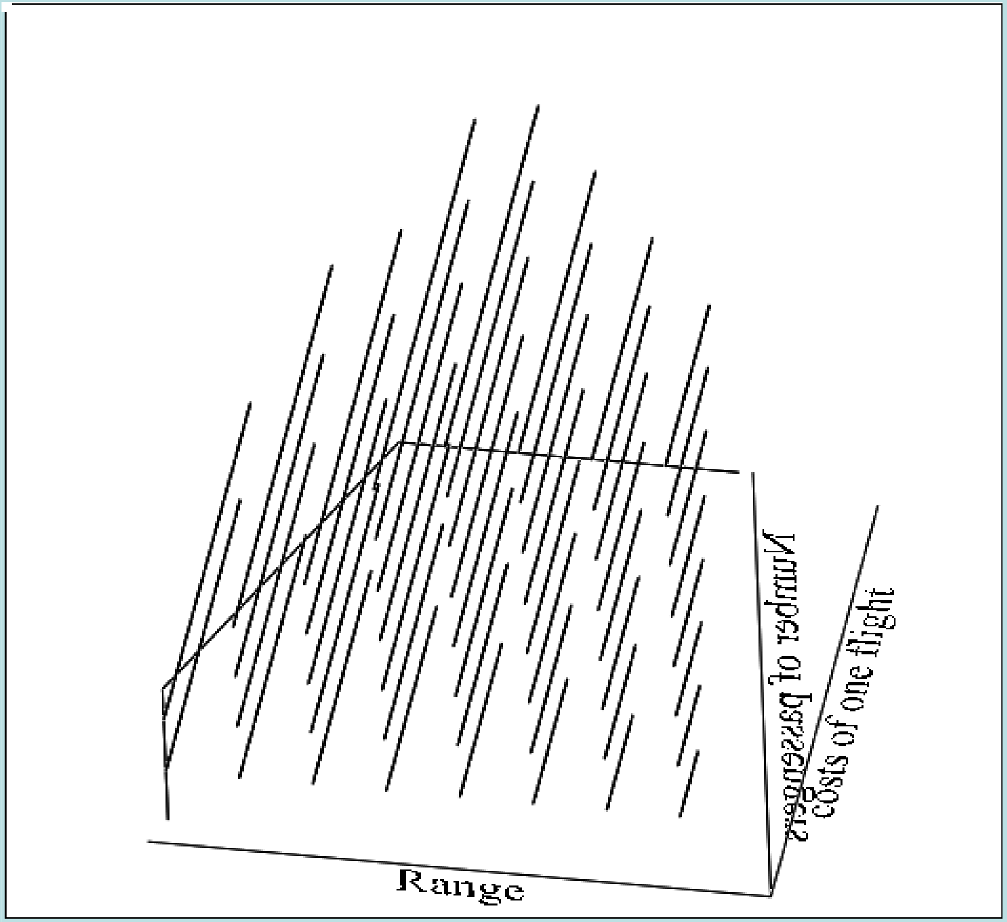
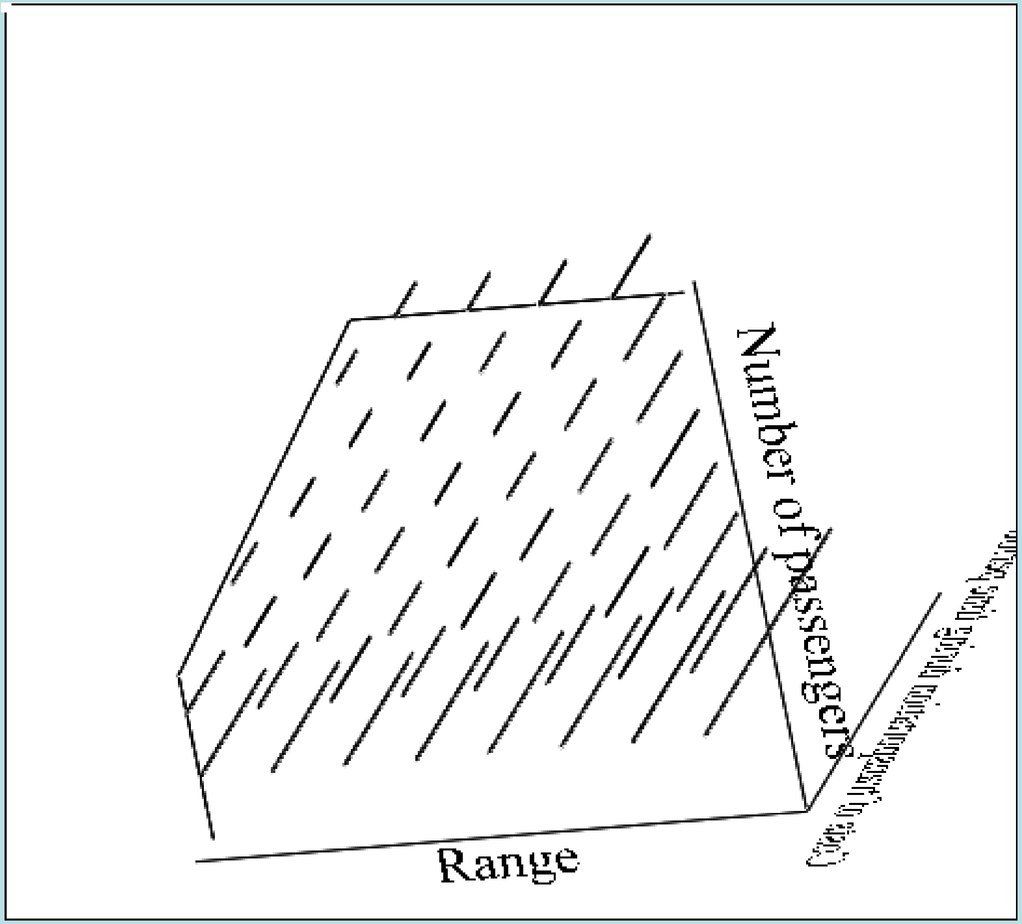
Dynamic problem of aircraft fleet creation and optimization.

- network changes with time (the shape and demand on the network change)
- such problem statement should also take into the account the introduction of new types into the fleet and writing-off (retirement) of old types from the fleet
- dynamic problem of aircraft fleet creation consists in solving a number of interconnected static aircraft fleet creation problems. Each of these problems should take into account the previous state of the optimized fleet (the solution of the previous static task) which are solved under various conditions for various years on a global time-scale. The process of solution of each static problem is conducted basing on the results of solution of the previous problems thus resulting in a global solution on the regarded global time-scale.
- the objective function $\boldsymbol{W_S}$ in this case are the total costs of carrying out passenger transportation over the global time period.

Aircraft fleet creation and optimization aspects. Dependence of flight costs and fleet costs on the range of flight and number of transported passengers



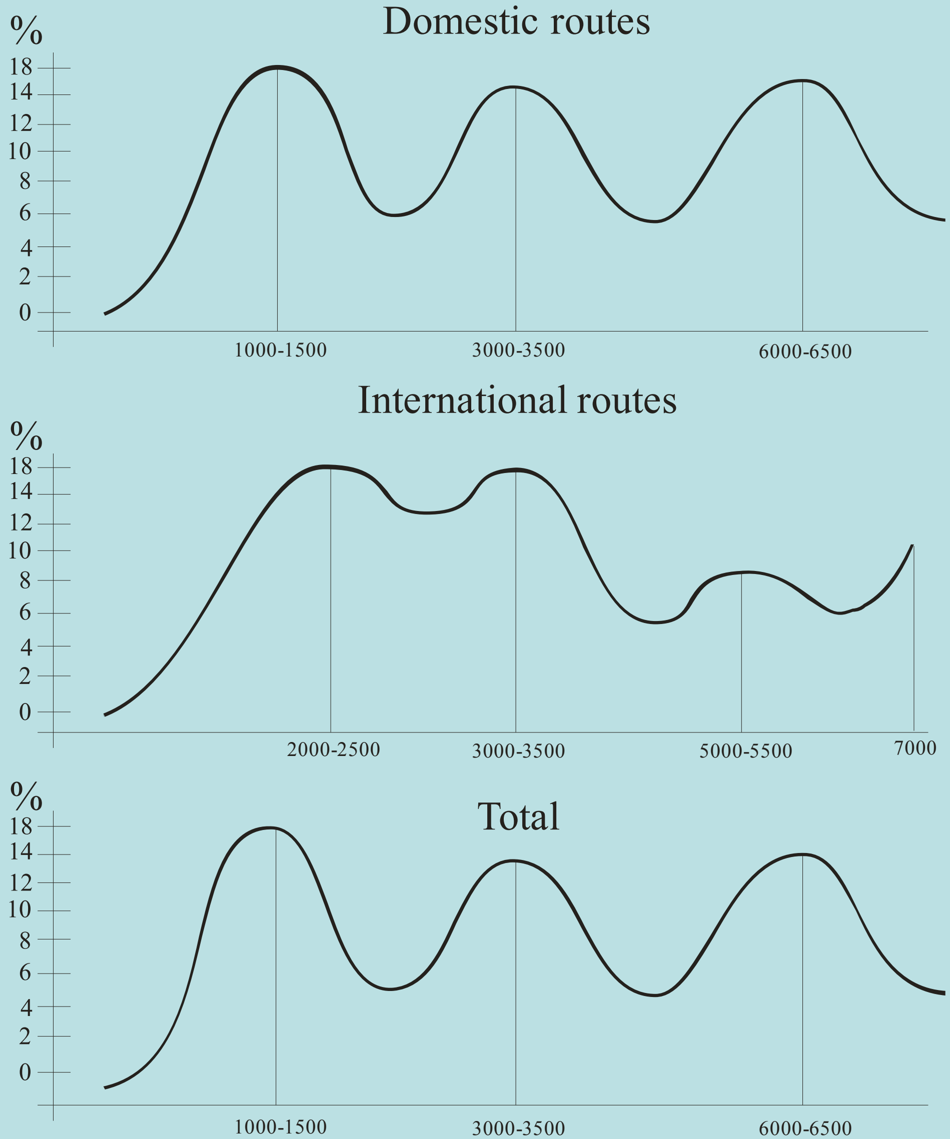
(linesx , linesy , zatr_rejs) , (planesx , planesy , planesz)



(linesx , linesy , zatr_god) , (planesx , planesy , planesz)

This slide shows how various details affect greatly the aircraft operation. For example, on this slide you can see how the costs of carrying out one flight and costs of carrying out passenger transportation during a long period of time change depending on range of flight and number of passengers onboard. Note that such dependency can only be achieved if we use a cost calculation method which takes into account indirect operational costs.Pavel Zhuravlev, Sevilla 2009

Aircraft fleet creation and optimization aspects. Example of distribution of passenger flow over flight range on domestic and international routes.



Change in passenger traffic flow distribution (peak shift) results in change of requirements for created and optimized passenger aircraft fleet.

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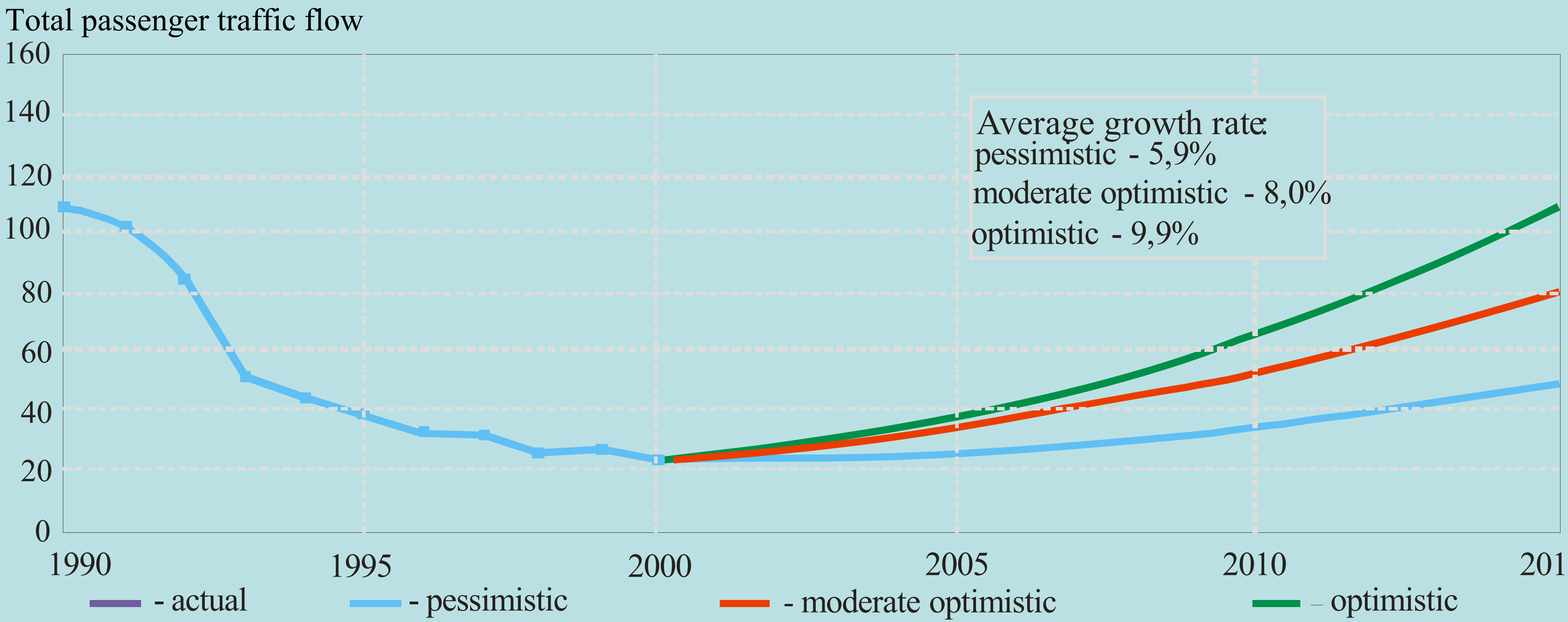
Aircraft fleet creation and optimization. Uncertainties in demand for the passenger transportation



Only range of values is normally given in forecasts for passenger air transportation demand. Therefore uncertainties in demand can be classified and regarded as z_1 (z_1 is the multitude of the uncertain factors (conditions), concerning which there is information only about the range of their values)

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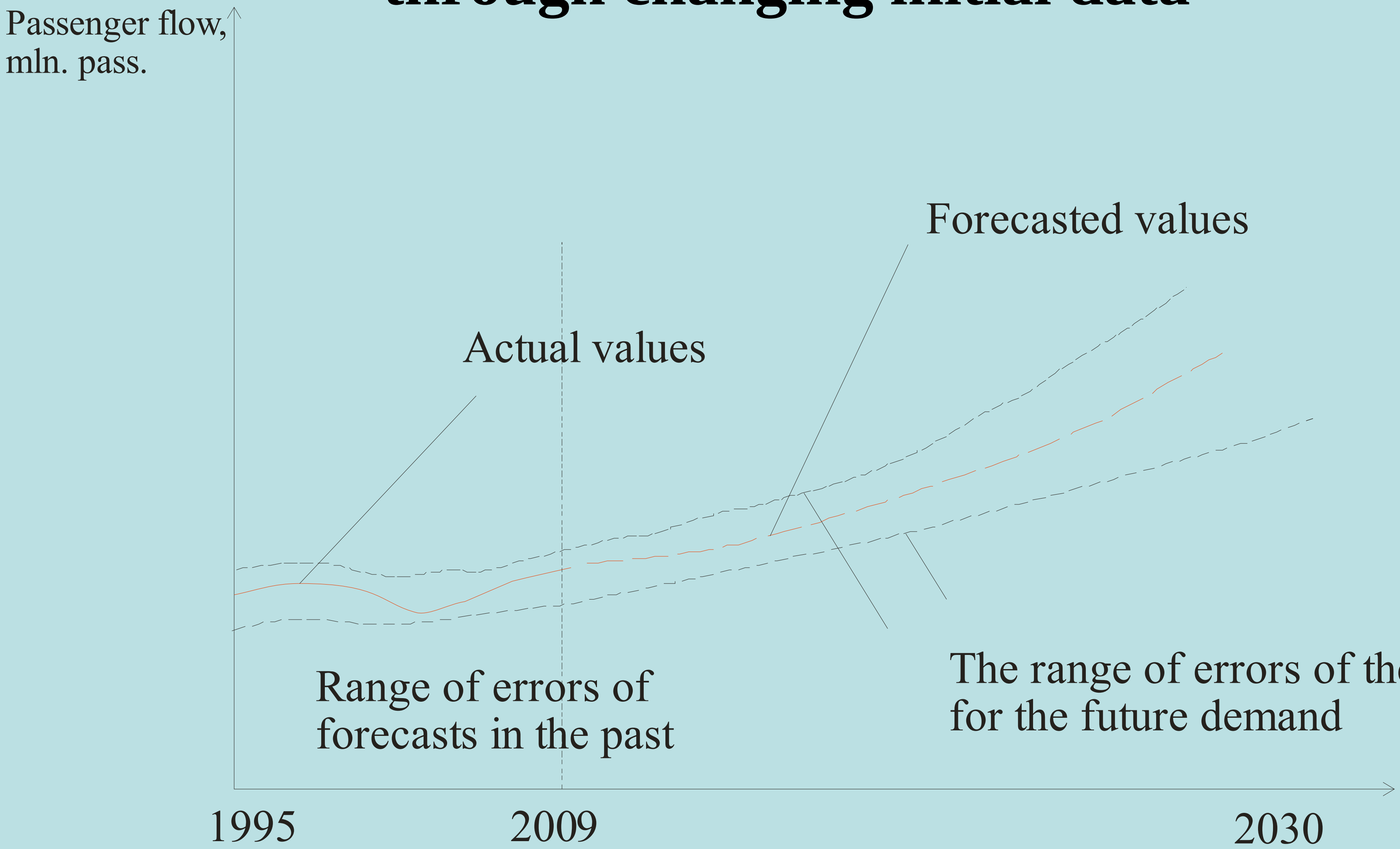
Estimation of robustness of the optimum aircraft fleet through changing initial data



Uncertainties of type z_1 can be estimated by modeling operation under the extreme conditions (extremely bad and/or good conditions).

Aircraft fleet creation and optimization. Schedule irregularities (breakdowns).

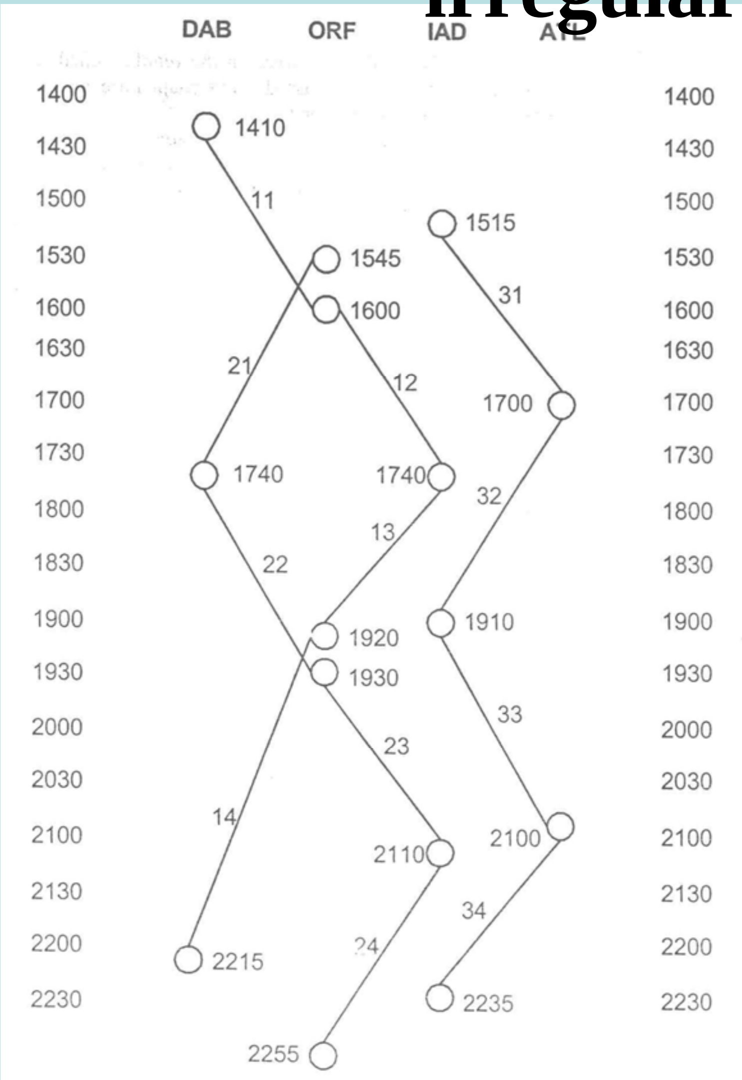


Figure 10.1 Time band network for the case study

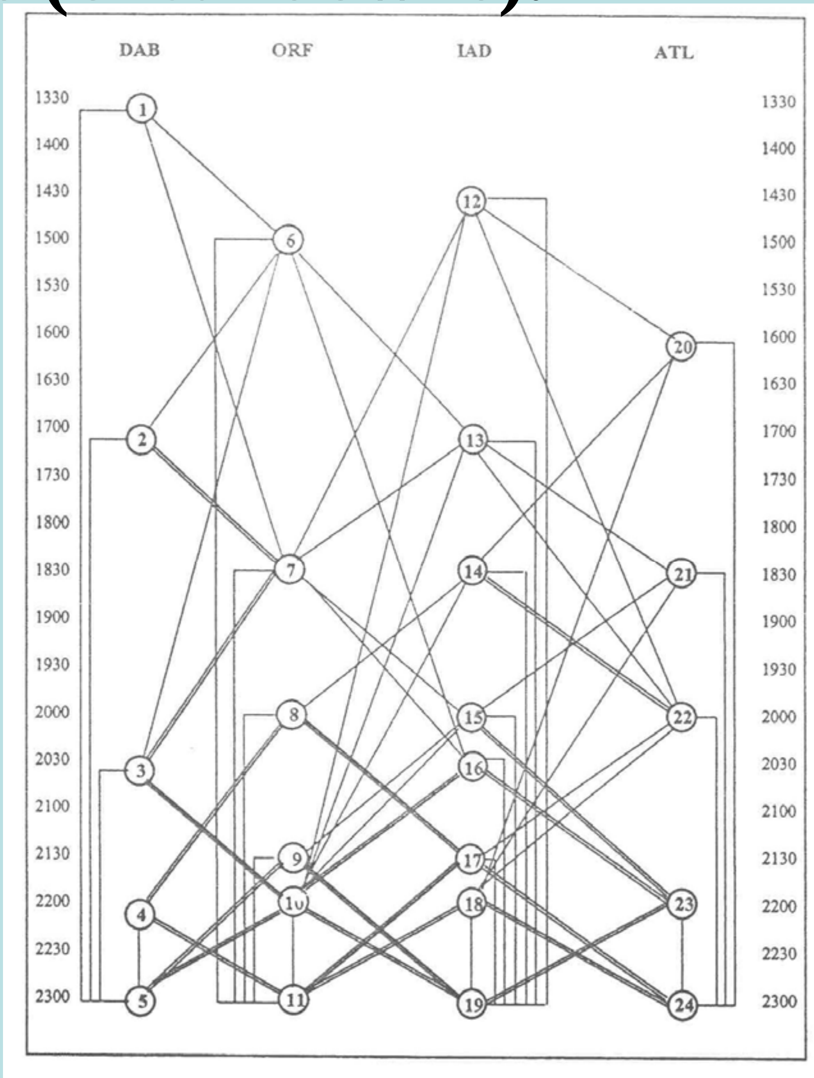


Figure 10.2 Time band approximation network

One of the examples of how many problems schedule breakdowns and irregularities cause for operators (airlines). It takes a lot of work to fix every particular irregularity.

Airlines Operations and Scheduling. M. Bazargan

Taking into account schedule irregularities.

- Since aircraft fleet creation is a long-term planning process it is necessary to find a way of taking into account all possible irregularities and airplane allocation shifts as a whole by means of mathematical modeling.
- This can be achieved by analyzing distribution of values of actual passenger quantities transferred in one flight by aircraft types (since this amount differs from one flight to another).

Taking into account schedule irregularities. Probability distribution.

Since there is information concerning the average utilization of an aircraft it is possible to say that the mean of distribution would be

$$M_{pasi} = \bar{N}_{pas_i}$$

where: M_{pasi} is the mean distribution

$\bar{N}_{pas_i}$ is the average aircraft utilization

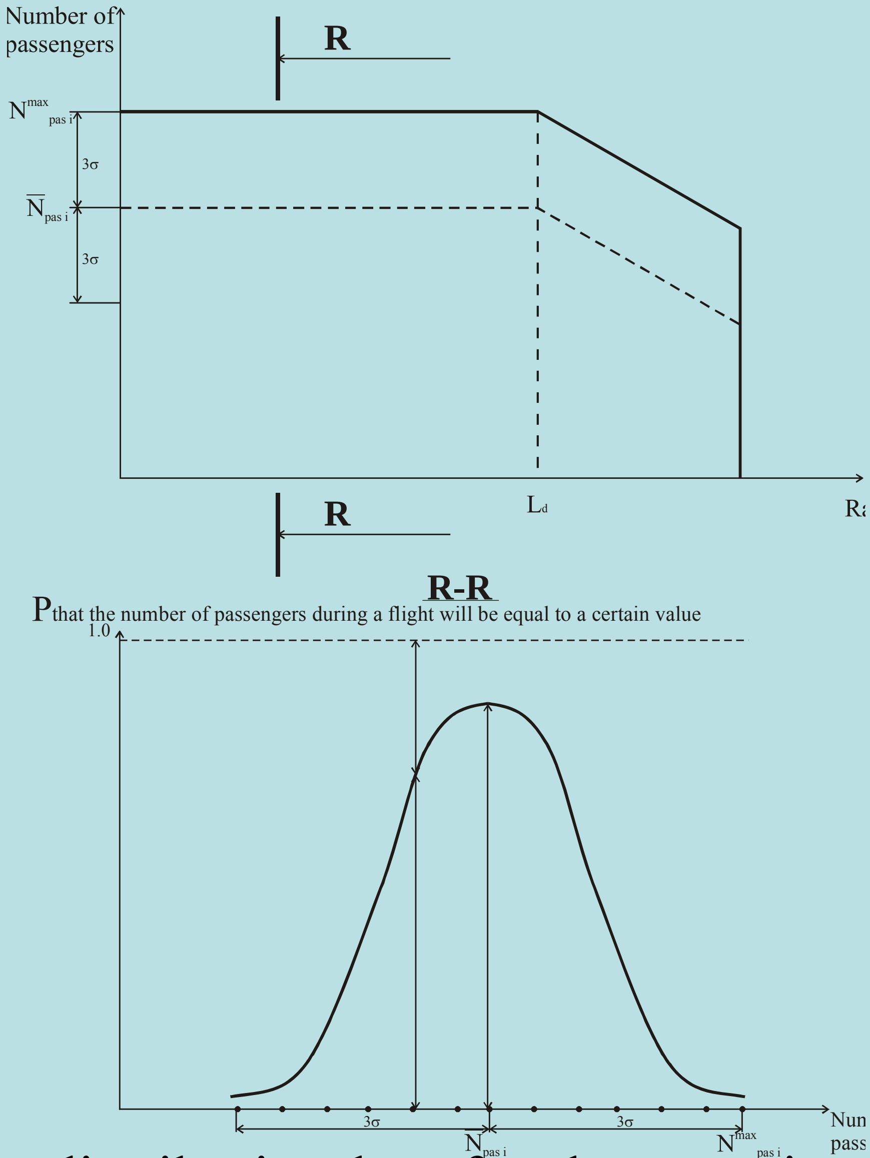
Since the quantity of passengers onboard cannot exceed the maximum capacity of an airplane it is possible to say that the standard deviation would be

$$3\sigma = N_{pas_i}^{max} - \bar{N}_{pas_i}$$

where:

$N_{pas_i}^{max}$ is the maximum capacity of an airplane

Aircraft fleet creation and optimization. Distribution of quantity of passengers in one flight.



Since we already know the distribution law for the quantity of passengers onboard during one flight we can classify this uncertainty as belonging to z_2 group.

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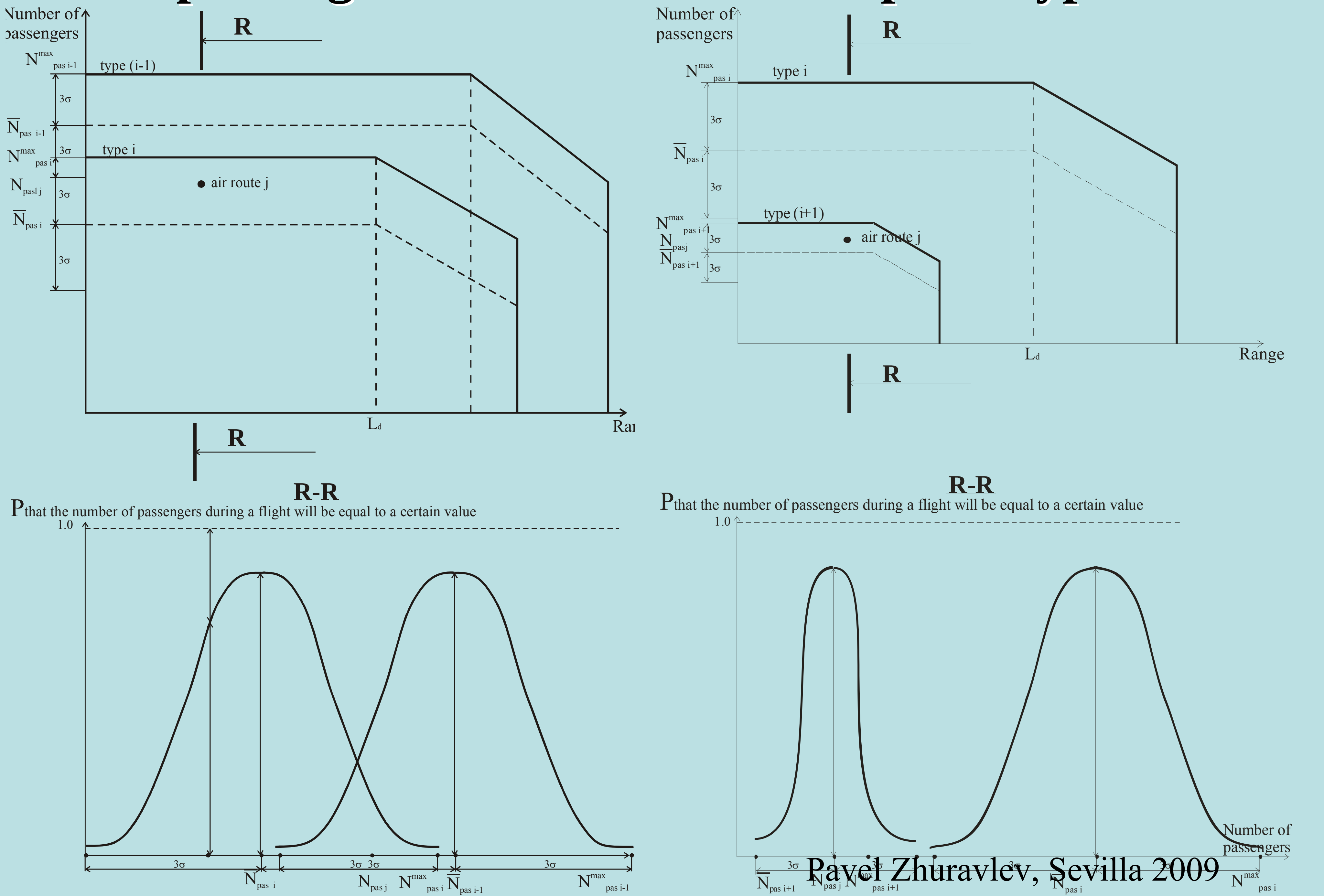
Aircraft fleet creation and optimization. Re-distribution of passengers between various airplane types.

- Besides carrying out passenger air transportation within the specialization area (***H_i***), every airplane has to carry out transportation on other routes as well. Therefore it is necessary to take into account that some transportation, which initially should have been carried out by smaller airplanes is actually carried out by bigger airplanes.
- Therefore it is necessary to take such transportation into the account basing on the available information.
- One of the important pieces of such information is the average fleet utilization. By using this value it is possible to create probability distributions for all airplane types and look at their interrelations.

Aircraft fleet creation and optimization. Re-distribution of passengers between various airplane types.



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The algorithm of passenger traffic flow redistribution

- First of all pairs of aircraft types are considered. The passenger traffic flow can be distributed from the aircraft type ***j*** both onto the bigger type (***i***-1) and/or smaller type of aircraft (***i***+1). The redistribution is made if the following conditions are met:

$$(\bar{N}_{pas_{i+1}} + 3\sigma < N_{pasj} < \bar{N}_{pas_{i+1}} - 3\sigma) \quad \text{and} \quad (\bar{N}_{pas_{i-1}} + 3\sigma < N_{pasj} < \bar{N}_{pas_{i-1}} - 3\sigma)$$

where:

N_{pasj} is the mean distribution for the type, from which the redistribution is made

$\bar{N}_{pas_{i-1}}$ is the mean distribution for the bigger type, onto which the redistribution is made

$\bar{N}_{pas_{i+1}}$ is the mean distribution for the smaller type, onto which the redistribution is made

The algorithm of passenger traffic flow redistribution

After that the amount of passenger traffic flow to be redistributed is calculated by the following formulas:

$$G_{redistj,i-1} = \frac{P_{i-1}\left(N_{pasj}\right)\cdot G_j}{\sum_{k=i_1}^{i_2} P_k\left(N_{pasj}\right)} \qquad G_{redistj,i+1} = \frac{P_{i+1}\left(N_{pasj}\right)\cdot G_j}{\sum_{k=i_1}^{i_2} P_k\left(N_{pasj}\right)}$$

where:

G_j is the value of passenger traffic flow for the type, from which the redistribution is made

$P_{i-1}\left(N_{pasj}\right)$ and $P_{i+1}\left(N_{pasj}\right)$ are the probability that the types (***i***-1) and (***i***+1) will carry onboard $\boldsymbol{N_{pasj}}$ passengers during the flight

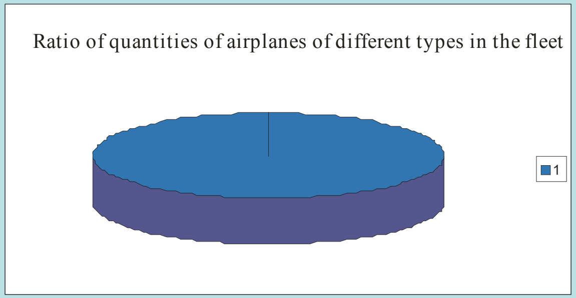
$\sum_{k=i_1}^{i_2} P_k\left(N_{pasj}\right)$ is the total sum of probabilities that all types will carry onboard $\boldsymbol{N_{pasj}}$ passengers during the flight

Passenger traffic flow redistribution

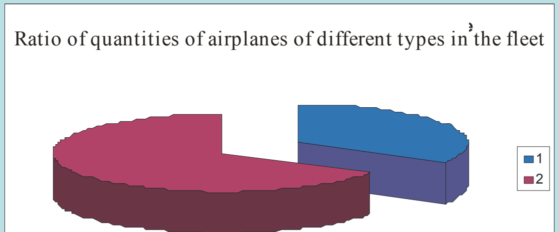
- It is necessary to mention that utilization of passenger traffic flow redistribution can change the total fleet costs for carrying out passenger transportation for more than 10%, which proves that this factor has a considerable influence over the fleet operation and should be taken into account.

Example of calculation results for one-type and two-type aircraft fleets.

	Type 1
Take-off weight, t	147
Wing area, m^2	278
Wing aspect ratio	6, 33
Wing leading edge sweep angle, deg	33
Wing thickness ratio near the fuselage	0, 118
Fuselage fineness ratio	7, 32
Flight cruising altitude, m	11500
Flight cruising speed, kmph	850
Number of seats in one row	9
Maximum number of passengers on board, man	251
Wing taper ratio	2, 08
Design flight range, km	7750
Maximum payload weight, t	27
Maximum flight range, km	8331
Mass of fuel required for flying over design range, t	43, 6
Mass of fuel required for long range cruise, t	55, 2
Operational empty weight, t	76, 3
Quantity of flight personnel members	2
Wing load	529
Power plant construction parameters	
Number of engines	4
Engine specific weight	0, 175
Number of engines with thrust reversing	4
Reversing degree	0, 6
Design Mach number	0, 9
Specific fuel consumption at H=0, V=0 kg/kg*h	0, 38
Engine unit-value, million dollars/t	1, 4
Power plant thrust, t	39, 3
Thrust of one engine, t	9, 83
Thrust-to-weight ratio	0, 267
Part in fleet, %	100



	Type 1	Type 2
Take-off weight, t	152	63
Wing area, m^2	280	123
Wing aspect ratio	7, 28	123
Wing leading edge sweep angle, deg	30	33
Wing thickness ratio near the fuselage	0, 118	0,183
Fuselage fineness ratio	7, 315	9,164
Flight cruising altitude, m	11500	10000
Flight cruising speed, kmph	850	793
Number of seats in one row	9	6
Maximum number of passengers on board, man	260	161
Wing taper ratio	2, 083	2,08
Design flight range, km	7750	4000
Maximum payload weight, t	26, 8	13,2
Maximum flight range, km	9582	5317
Mass of fuel required for flying over design range, t	43, 2	14,5
Mass of fuel required for long range cruise, t	54, 4	20, 3
Operational empty weight, t	77, 26	31,6
Quantity of flight personnel members	2	3
Wing load	524, 83	480
Power plant construction parameters		
Number of engines	4	2
Engine specific weight	0, 175	0,21
Number of engines with thrust reversing	4	2
Reversing degree	0, 6	0, 6
Design Mach number	0, 9	0, 9
Specific fuel consumption at H=0, V=0 kg/kg*h	0, 38	0, 45
Engine unit-value, million dollars/t	1, 4	1, 4
Power plant thrust, t	31, 4	18,4
Thrust of one engine, t	7, 85	9, 2
Thrust-to-weight ratio	0, 206	0, 292
Part in fleet, %	27, 6	72,4



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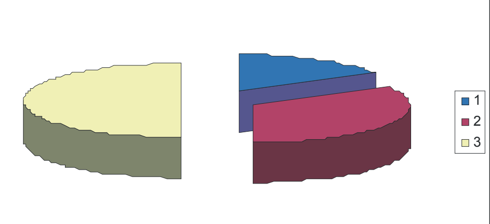
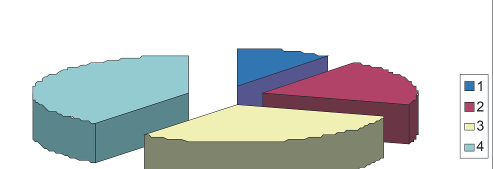
Example of calculation results for three-type and four-type aircraft fleets.

	Type 1	Type 2	Type 3
Take-off weight, t	175	104	60
Wing area, m^2	271	152	100
Wing aspect ratio	8, 8	11, 4	6, 9
Wing leading edge sweep angle, deg	16, 8	25,4	40, 2
Wing thickness ratio near the fuselage	0, 172	0,187	0, 112
Fuselage fineness ratio	7, 03	8,83	9, 1
Flight cruising altitude, m	11500	10150	9210
Flight cruising speed,kmph	850	834	762
Number of seats in one row	9	6	6
Maximum number of passengers on board, man	251	151	159
Wing taper ratio	2, 08	2,08	2, 08
Design flight range, km	7750	8000	2500
Maximum payload weight, t	21	16,4	15, 7
Maximum flight range, km	8016	9000	4446
Mass of fuel required for flying over design range, t	68	27,5	6, 2
Mass of fuel required for long range cruise, t	77	34, 5	13
Operational empty weight, t	83	49	38
Quantity of flight personnel members	2	2	2
Wing load	646	684	600
Power plant construction parameters			
Number of engines	2	2	3
Engine specific weight	0, 175	0,175	0, 175
Number of engines with thrust reversing	2	2	3
Reversing degree	0, 6	0, 6	0, 6
Design Mach number	0, 9	0, 9	0, 9
Specific fuel consumption at H=0, V=0 kg/kg*h	0, 36	0, 38	0, 35
Engine unit-value ,million dollars/t	1, 4	1, 4	1, 4
Power plant thrust, t	56, 3	25,5	17, 1
Thrust of one engine, t	28, 1	12, 7	5, 7
Thrust-to-weight ratio	0, 322	0, 245	0, 285
Part in fleet, %	23, 4	16,2	60, 4



Ratio of quantities of airplanes of different types in the fleet

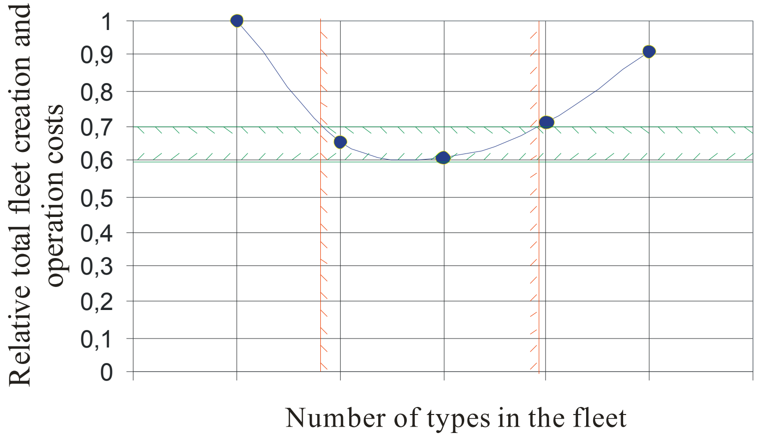
	Type 1	Type 2	Type 3	Type 4
Take-off weight, t	180	108	69	48
Wing area, m^2	271	215	168	101
Wing aspect ratio	8, 82	8, 9	9, 01	11
Wing leading edge sweep angle, deg	16, 85	25, 68	34,78	30, 5
Wing thickness ratio near the fuselage	0, 172	0, 174	0,16	0, 196
Fuselage fineness ratio	7, 03	7, 03	8,83	7, 32
Flight cruising altitude, m	11500	11500	10800	10200
Flight cruising speed,kmph	850	825	810	745
Number of seats in one row	9	9	6	6
Maximum number of passengers on board, man	251	150	160	108
Wing taper ratio	2, 08	2, 08	2,08	2, 08
Design flight range, km	7750	7750	4000	2000
Maximum payload weight, t	21	16	14	10
Maximum flight range, km	8500	8300	5600	3500
Mass of fuel required for flying over design range, t	68	42	20	15
Mass of fuel required for long range cruise, t	77	50	27	19
Operational empty weight, t	83	50	45	31
Quantity of flight personnel members	2	2	2	2
Wing load	664	591	411	475
Power plant construction parameters				
Number of engines	2	2	2	2
Engine specific weight	0, 175	0, 175	0,175	0, 175
Number of engines with thrust reversing	2	2	2	2
Reversing degree	0, 6	0, 6	0, 6	0, 6
Design Mach number	0, 9	0, 9	0,9	0, 9
Specific fuel consumption at H=0, V=0 kg/kg*h	0, 36	0, 36	0,38	0, 4
Engine unit-value ,million dollars/t	1, 4	1, 4	1,4	1, 4
Power plant thrust, t	56, 3	38, 7	22,4	15, 2
Thrust of one engine, t	28, 15	19, 4	11, 2	7, 6
Thrust-to-weight ratio	0, 313	0, 3	0, 32	0, 32
Part in fleet, %	23	11, 3	57,1	8, 6



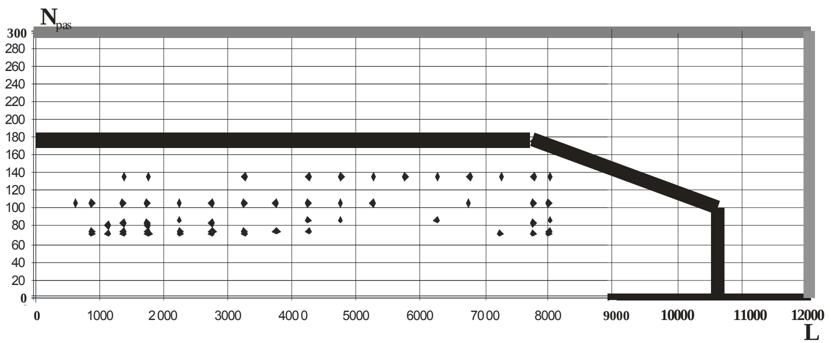
Ratio of quantities of airplanes of different types in the fleet

Pavel Zhuravlev, Sevilla 2009

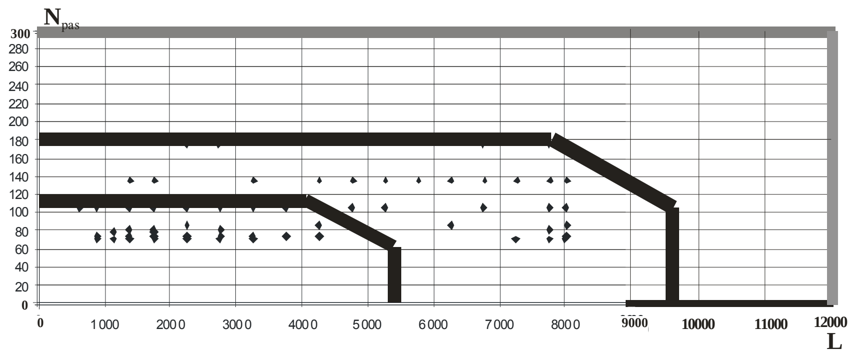
Example of analysis of the calculation results.



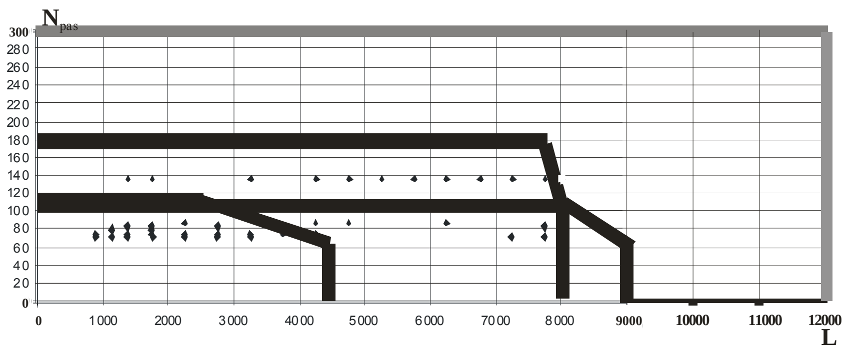
m_0 147



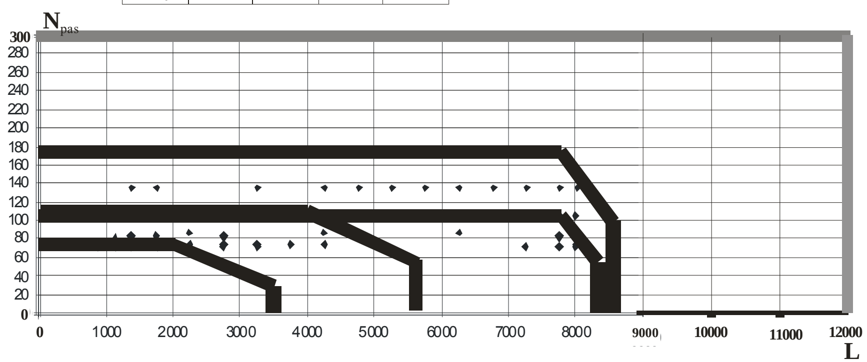
m_0 152 63



m_0 175 104 60



m_0 180 108 69 48



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Conclusions

- A method has been developed for creating and optimizing the performance and parameters of passenger aircraft with taking into account their operation within a complex passenger air transportation system (multi-type aircraft fleet)
- This method also allows testing various new concepts of aircraft.
- The offered approaches allow to solve both the static problem (for a short limited period of time – “time-slice”) and dynamic problem of optimization of aircraft fleet (optimization with taking into account the long-term functioning peculiarities).
- The appropriates methods were introduced for taking into account the uncertainties of forecasts and conditions of operation of the created aircraft fleet.

Thank you for your attention.
Are there any questions?