

# Color optical computing frameworks for decision support in transport control systems

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## Abstract

Improving the safety of large-scale transportation processes — air, maritime, and similar infrastructure operations — considering the human factor in conditions of extreme traffic saturation, high technical complexity of vehicle designs, and varying intensity of external weather disturbances, forms a multi-criteria problem of decision-making by a human operator (pilots, dispatchers, and port controllers) with rapidly changing big input data. An approach to constructing hierarchically organized structures of a decision support system is proposed using the example of aircraft control in takeoff mode. The synthesis of the decision support system is based on the use of ranked fuzzy input data in the form of color information quanta and optical color computing structures. The advantages of the optical computing architecture are high-speed information processing, ease of implementing parallel structures and informative visualization of output decisions for a human operator. The implementation of possible trajectories of the decision-making process for various combinations of input data is presented.

## Keywords

optical color computing architecture, color information quanta, decision support system, transport control system

## 1. Introduction

The rapidly increasing volume of information in managing extensive infrastructure transport facilities significantly affects the safety of their operation in technological and, especially, critical situations. For example, to ensure the safety of navigation and cargo operations when managing the seaport of Rotterdam with an annual ship call of more than 30,000 ships (from open sources), it is necessary to take into account many factors, including assessments of weather conditions and the state of the channel, traffic intensity, technical characteristics of ships, the condition and qualifications of the crew, pilotage and dispatch services, etc. Such problems arise to an even greater extent at large airports. At one of the largest airports in the USA, in the city of Atlanta, in some years the number of takeoffs and landings approached one million per year (from open sources), i.e., every 2 minutes. The volumes of information affecting transport-system safety — and air traffic safety in particular — include the following technical, human and organizational data [1-4]: technical and other parameters of each aircraft and its crew/passengers located in the area of responsibility of a given airport; complex and current meteorological conditions; technical condition of runways; features of the airport terrain; functionality (staffing and qualifications) of the control service. The amount of data for each of the positions considered can reach hundreds of values. In combination with the extremely high dynamics of technological processes (for example, in the AIRBUS

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instructions [4], the time for the decision-making by the crew commander between the occurrence of an engine failure and the permissible (safe) interruption of the flight is 1 second), this can lead (generalized statistics of air accidents from open sources confirms this) to significant tragic errors by the human operator (aircraft pilots and dispatchers). Developing intelligent decision support systems is intended to help solve the above problems. The principles of building a decision support system (DSS) for managing the safety of various technological processes are based on the following aspects: defining an array of key factors, as well as the parameters included in them, that shape the safety of the process; ranking each factor by the significance of its impact on safety; forming an array of expert safety assessments; formalizing possible decisions of a human operator (dispatcher); basic logical rules for the logical inference of decisions (assessments); choosing structural constructions of hierarchical multi-level inference networks; assessing the effectiveness of decision-making processes from the point of view of the truth of the decisions made by the system. The development of intelligent decision support systems includes various inference mechanisms based on specific rules, precedents, forming a matrix of ranked assessments, etc. [5-6]. Decision making under uncertainty is based on a qualitative evaluation of factors and their component parameters using a large sample of statistical data and probabilistic analysis methods. For example, the following techniques are used in navigation safety control tasks based on decision support systems: risk-oriented approaches to assessing safety factors; the concept of changing the maneuvering rate when moving along a given trajectory; dynamic games in the DSS navigation safety navigator; a modified high-speed obstacle method for synthesizing a ship collision warning system [7-10]. The theory of fuzzy sets and fuzzy logic [11,12] is widely used in the formation of high-quality information databases and logical inference systems, in transport logistics problems, and in planning the trajectories of ships in limited water areas under conditions of increased traffic intensity and significant external disturbances [13].

The purpose of this work is to develop a high-speed optical computing architecture for decision support in critical control processes for complex transportation systems with big data. Among the transportation sectors, the multifactorial and multiobjective nature, rapid change of the current situation, and the responsibility of air traffic control present the most challenging cases for the synthesis of decision support systems. In air traffic safety risk control [2], the following key stages are distinguished: preflight preparation; aircraft takeoff; the main flight; and aircraft landing. Each stage involves varying degrees of interaction between the pilot and the flight controller (more intense during takeoff/landing and less intense throughout the flight). These stages combine a multitude of heterogeneous input parameters, the highly dynamic nature of the controlled process, and strict time constraints on the operator's decisions. In such conditions, the advantages of optical computing systems such as data processing speed, virtually unlimited parallelism of information input, and immediate visual interpretation of output data are crucial: the operator can quickly determine which parameters are approaching a dangerous range and make the optimal, safe decision. In this paper, using the technological operation of take-off of an AIRBUS aircraft [4] as the representative case, we determine the main safety factors and synthesize the structure of a practical computational architecture of the DSS for logical inference of decisions. The tasks of the DSS in air traffic risk control are regulated by International Civil Aviation Organization (ICAO) documents [2,3], which include problems of increasing the efficiency of human-machine interaction during flight performance and are divided into subtasks of avionics (aircraft control) and air traffic control service. It is important to note the need for a comprehensive consideration of static (a priori specified) parameters and their combination with dynamically changing air traffic parameters. In the field of avionics, researchers are devoted to creating intelligent crew support systems to improve the safety of aircraft flights by reducing the level of emergency situations [14-17]. An intelligent crew support system contains the primary sensors: engine status, fuel system, hydraulic system, power supply system, chassis release and braking system, anti-icing system, fire extinguishing system, flight altitude, and also includes a satellite and inertial navigation system, an instrument landing system, an information display system, a takeoff run control system), a warning system about dangerous proximity to the ground, a warning system about reaching hazardous values of the angle of attack

and overload, a landing approach and landing control system, a wind shear warning system. Increased efficiency of decision-making processes is achieved by expanding technical capabilities, including using a non-aviation computing device [17]. It is also important to identify potentially unsafe combinations of risk factors based on, for example, a high level of unified modelling framework for various incidents using specialized SysML software, followed by an assessment of the combined impact of these indicators on the overall safety of the system [18]. The widespread use of unmanned aerial vehicles for cargo transportation and other auxiliary aviation tasks also requires developing a safety support system for specialized road safety risk control [19-23]. Research in the field of creating effective DSS for managing aircraft movement at airports is based on: expanding the factors influencing decision-making by a human operator and taking into account technical, physiological, psychological and psychosocial aspects of the work process [24]; constructing models for representing precedents (knowledge) about the development of possible emergency situations in critical modes [25]; and increasing the level of planning for aircraft maintenance checks [26]. It should be noted that the development of DSS for large objects with big data faces many problems. These are primarily insufficient computational speed of traditional algorithms for processing information and making possible decisions for highly dynamic processes, limited parallel computing capabilities, and visualization of current input and output information, which is inconvenient for quick perception. The problem of increasing the performance of computer calculations is a pressing issue in almost all aspects of the application of decision support systems in conditions of extremely large, real-time changing input data. The article [27] proposes principles for constructing a decision support system for managing intense maritime traffic in restricted waters, based on the use of optical color computing. The proposed approach appears promising for much more multifactorial and highly dynamic DSS processes in air traffic control. The use of modern optoelectronic technologies to increase computing performance and transmit information is of interest. There are two main areas in the development of optical computing: optoelectronic logic devices that combine the advantages of optical and semiconductor components, using semiconductor keys for binary coding and calculations; construction of all-optical logic devices based on the properties of interference, polarization and coherence of a light beam, as well as using the properties of diffraction gratings and photonic crystals. Works [28-35] in this direction show (a) the energy efficiency of optical architecture, (b) the structural possibility of parallel computing, (c) high speed of information processing, (d) resistance of computer networks to interference, etc. At the same time, there is a problem of the complexity of the technological implementation of optical architecture based on such physical processes as diffraction, polarization and interference [36-39]. The need to use devices for measuring the characteristics of light waves, complex lasers and systems of matrix prisms, movable structural elements, and several other difficulties, slows down the widespread implementation of such optical components. It is also important to note that the main focus of most studies in the field of optical computing is on binary computing operations, which for humanistic (intellectual) decision-making problems, leads to a significantly excessive volume of processed information compared to the use of directly fuzzy (qualitative) input information. It can be shown that the requirements for computations to be both fast and noise-resistant naturally lead to color-based optical computing [40]. In works [41-44], the authors proposed an alternative way to construct a computational optical architecture focused on logical computational operations directly with fuzzy input data. A comparative analytical estimate of the proposed approach to logical operations on fuzzy data shows an approximately 30-fold performance improvement over the FPGA architecture as reported in [45].

The scientific novelty of this work lies in the development of a high-performance optical architecture for decision-making systems with large volumes of fuzzy input data. This architecture represents input/output information as optical quanta of a specific color and processes them logically according to the physical laws of colorimetric transformation. The advantages of the proposed approach are the non-commutative composition of logical stages, light-speed processing, and efficient computing networks based on parallel fiber-optic structures. Thus, when synthesizing DSS

for large transportation facilities, it becomes possible to significantly improve information processing performance and optimize the visualization of output information for operators.

## 2. Main Ideas and Objectives of Research

In considering the formation of various decision-making trajectories, let us assume that the simplest (ordinary) decision is made on the basis of logical summation (disjunction operation) of three supposedly independent assessments (A, B, C, see Figure 1). This naturally follows from the possibility of making a decision on the basis of one or two assessments and the disadvantage of this process, which consists, first of all, in the extreme minimality of the information volume of the input data, which sharply increases the probability of making an erroneous decision. In addition, in the case of only two assessments, a situation of directly opposite assessments is likely, which actually means the absence of a satisfactory decision. What do three assessments give, as a minimum of the necessary input information? First of all, the third assessment will resolve the situation with the two opposite assessments. Further, three identical assessments sufficiently increase the confidence in the decisions based on these assessments. The computational process takes minimal time for simple (non-critical, not carrying serious consequences) real-time decision-making tasks. Continuing to form the decision-making process, we will imagine the initial stage of this process as summing (accumulating) the input information. In the process of logical inference, it is necessary to take into account the property of idempotence for disjunction and conjunction operations with identical information sets  $Q$

$$Q \vee Q = Q; Q \wedge Q = Q,$$

as well as a sufficient level of alternativeness of combinations of different assessments, it is rational to use a logical structure with three additional parallel branches, each of which contains two filtering assessments (G, H, I, J; K, L) and forms a logical conjunction operation. Then the three obtained solutions are summed up by means of a logical disjunction operation. For the final phase of decision-making with the assessments of responsible experts, which allow, among other things, to block the output decision, a sequence of corresponding filters (D, E, F) is proposed as a process of filtering (subtracting doubts) of the decision based on the logical operation of conjunction. Thus, the amount of input information in the form of certain sets is expanded to 12 (Figure 1).

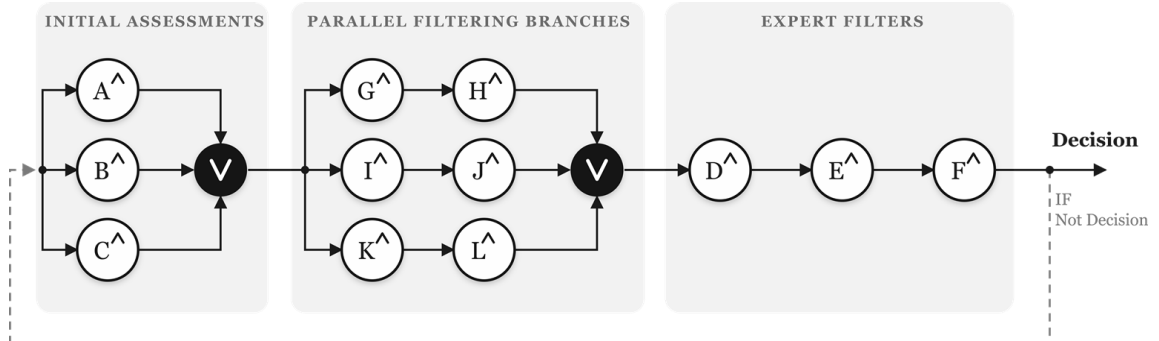


Figure 1: Extended logic diagram for decision-making (the superscript indices  $\wedge$ ,  $\vee$  define the conjunction and disjunction operations respectively).

Continuing with the application of the thought modeling of the decision-making process, let us consider the possibilities of the proposed logical structure for more complex tasks, for example, a local solution for the dispatch service for managing the movement of sea vessels in conditions of limited water areas (shipping channels, terminals, ports) with intensive navigation traffic [27]. The most important factors influencing the safety of navigation and the corresponding decision on the possibility and parameters of vessel movement in the shipping channel include (using the example of the Bug-Dnieper estuary canal ) weather conditions, type of cargo and type of vessel, condition of the vessel and crew: wind speed; time of day; visibility; kind of cargo; actual draft; maximum length

of the boat; age of the vessel; classification of the vessel by destination; ship condition; season; time of continuous work of the crew; the number of ships in the channel moving in the opposite direction. The initial three main factors for decision-making include weather conditions: wind speed, time of day and visibility. Further, it is advisable to consider the following six factors in alternative evaluation: type of cargo, actual draft, maximum length of the vessel, age of the boat, classification of the vessel by destination, and ship condition. Finally, the critical responsible assessments in the longitudinal decision-making chain include the season, the time of continuous crew work, and the number of vessels in the channel moving in the opposite direction. The decision-making process proceeds as follows: at the first stage, the three primary assessments are summed up; for example, with one negative assessment and two positive ones, we obtain a total positive assessment; the second stage of the logical process with the help of alternative assessments in three parallel channels makes it possible to make a positive conclusion with positive assessments only in one channel and block decisions in the other two channels; the third stage is the responsible conclusion of the final decision, since any of the three assessments can block a positive final decision; in the event of blocking the final decision, the evaluation process must be continued, starting from the first stage by changing (softening) the preliminary negative assessments. In the air transportation industry, the specific task of using a decision support system for a pilot and/or a dispatcher who operates under extremely limited time and makes critical decisions requires a combination of three things: high computing speed, a visually convenient system for input and output of information, and rapid optimization of possible solutions in emergencies. The works [43] consider implementing components of two-level decision-making systems to improve navigation safety in large infrastructure port technological complexes and the efficiency of family health services. The creation of multi-level decision support systems for transport infrastructure with intensive traffic is of significant interest in improving operational safety, with aircraft traffic control at large airports standing out as one of the most demanding cases. In addition to the obvious relevance of this task, this interest is supplemented, firstly, by the task's high multicriteria and a large number of safety factors; secondly, by the need for real-time control since, as stated in the ICAO manual, "the time allotted to the air traffic controller to recognize a potential threat of collision in an abnormal situation during simultaneous approaches to parallel runways is measured in seconds" [2-4].

The general task of decision-making in aircraft movement control includes a relatively independent subtask of decision-making during pre-flight preparation of an aircraft for flight, and two interdependent subtasks of controlling an airplane's primary flight and its take-off/landing at airports with different functional technological capabilities and the complexities of the surrounding terrain. As an innovative basis for constructing multi-level decision support systems, the authors [41-43] proposed a representation of input information sets in the form of corresponding fuzzy color quanta of information and an optical computing architecture that implements the basic logical operations of disjunction, conjunction, negation and their union. The advantages of the developed optical architecture are high computing performance due to the speed of light in the components, natural parallelization of optical multi-level structures, low power consumption, noise resistance and clear visualization of output information for a human operator. The stated objective will be achieved by using the advantages of optical color computing: high speed of information processing; an effective form of presentation (visualization) of output decisions; and optical structural implementation of alternative solutions that increase the safety of aircraft control. It should also be noted that although the data for the formation of input information in such a task is used from the current regulatory flight documentation, the task of the study is seen in the formation of an approach to the construction of a decision support system with corresponding examples of modeling, naturally, not claiming to be complete in the creation of specific components of the prototype and requiring more in-depth specialized development. The considered example of implementing a database based on factors determining the safe takeoff of an aircraft uses Flight Operations Support & Services/ Introduction to Aircraft Performance/ Airbus/2007 [4]. Of interest to researchers in the field of creating DSS are technological objects with large input data and with a functioning process

that quickly changes over time. Therefore, this object of study and example was chosen proactively. It is a scientific implementation and is not directly connected at this stage with practical implementation.

### 3. Basic Principles of Color Optical Computing

#### 3.1. Representation of a Fuzzy Database

ICAO documents [2] regulate several gradations of assessments. For the probability of occurrence of emergencies, five levels are defined (Table 1). Safety risk severity is classified into five levels as well (Table 2).

Table 1  
Probability of occurrence of emergencies (ICAO [2])

| Code | Term                 | Description                     |
|------|----------------------|---------------------------------|
| 5    | Frequent             | Likely to occur many times      |
| 4    | Occasional           | Likely to occur sometimes       |
| 3    | Remote               | Unlikely to occur, but possible |
| 2    | Improbable           | Very unlikely to occur          |
| 1    | Extremely improbable | Almost inconceivable            |

Table 2  
Safety risk severity assessments (ICAO [2])

| Code | Term         | Description                                                |
|------|--------------|------------------------------------------------------------|
| A    | Catastrophic | Equipment destroyed; multiple deaths                       |
| B    | Hazardous    | Significant reduction in safety margins (equipment damage) |
| C    | Major        | Significant reduction in safety margins (serious incident) |
| D    | Minor        | Nuisance; operating limitations                            |
| E    | Negligible   | Few consequences                                           |

Based on the matrices of the relationships between the two factors, the risk index is determined and regulatory decisions and corresponding situation control are formed: red level (for example, 5B) — unacceptable under the existing circumstances; yellow level (4C) — acceptable based on risk mitigation, it may require a control decision; green level (2D) — acceptable. The idea of representing a fuzzy set of situation assessment in the form of a color quantum is based on the strict construction of logical relations of color sets relative to the concepts of truth and false of a given process of logical inference of a decision on its positivity (for example, safety). The authors of [27, 46] proposed to represent the sequence of the true operand Y and the false operand N by logical evaluations

transformed into color quanta: red {R} – no (N); green {G} – probably yes (YN); blue {B} – yes (Y); white {W} – positive decision (YYNN); light blue {C} – very likely yes (YYN); purple {M} – probably no (NY); yellow {Yel} – very likely no (NNY); black {Blc} – no decision (0). The principles for the formation of fuzzy color databases of transport-system safety factors – illustrated below for aircraft traffic – should take into account the experience of applying current ICAO regulations and allow, with a significant degree of detail, to rank hazards according to the degree of impact on safety, expand the functionality of output systems based on color optical logical networks, and fundamentally improve the visualization of the traffic control process using color information about dangerous traffic zones and aircraft states. An example of constructing a component of a color fuzzy information base for assessing the safety of an aircraft takeoff situation is described as follows in Table 3.

**Table 3**  
Fuzzy color database of safety factors for aircraft takeoff

| №  | Factor (units)                    | Most favorable              | Intermediate               | Least favorable      |
|----|-----------------------------------|-----------------------------|----------------------------|----------------------|
| 1  | Cross wind speed                  | Light – {B}                 | Moderate – {G}             | Strong – {R}         |
| 2  | Aircraft type                     | Four engine wide-body – {B} | Twin engine aircraft – {G} | Light aircraft – {R} |
| 3  | Dispatcher qualification          | High – {B}                  | Medium – {G}               | Low – {R}            |
| 4  | Snow, cm                          | 0–2 – {C}                   | 2–5 – {M}                  | > 5 – {Yel}          |
| 5  | Time of day                       | Daylight – {C}              | Dark – {M}                 | Night – {Yel}        |
| 6  | Flight intensity                  | Low – {B}                   | Medium – {M}               | High – {Yel}         |
| 7  | General condition of the aircraft | Good – {C}                  | Satisfactory – {M}         | Acceptable – {Yel}   |
| 8  | Number of aircraft in front       | 1 – {C}                     | 2–3 – {M}                  | > 3 – {Yel}          |
| 9  | General condition of the pilots   | Good – {C}                  | Medium – {M}               | Acceptable – {Yel}   |
| 10 | Crew qualification (+2 pilots), h | ≥ 10 000 – {C}              | 5 000 – 10 000 – {M}       | ≤ 5 000 – {Yel}      |
| 11 | Visibility, m                     | > 1600 – {C}                | 700 – 1600 – {M}           | < 700 – {Yel}        |
| 12 | Staffing of the dispatch service  | Full – {C}                  | Medium – {M}               | Low – {Yel}          |

### 3.2. Basic Logical Color Operations

Fundamental logical operations are proposed to be formed based on colorimetric transformation of visible spectrum light emitter [41-43]. It is convenient to use the description of the primary (RGB) and additional (YelCM) colors, as well as white emitter {W} and absence of radiation {Blc} in the form of diagonal matrices:

$$\begin{aligned}\{R\} &= \text{diag}(R, 0, 0); \{G\} = \text{diag}(0, G, 0); \{B\} = \text{diag}(0, 0, B) \\ \{Yel\} &= \text{diag}(R, G, 0); \{C\} = \text{diag}(0, G, B); \{M\} = \text{diag}(R, 0, B) \\ \{W\} &= \text{diag}(R, G, B); \{Blc\} = \text{diag}(0, 0, 0).\end{aligned}$$

The application of basic logical operations such as disjunction and conjunction in the context of color mathematics is described in the following examples of equations in matrix form:

- disjunction

$$\text{diag}(R, 0, 0) + \text{diag}(0, G, 0) = \text{diag}(R, G, 0), \quad (1)$$

$$\text{diag}(R, 0, 0) + \text{diag}(0, G, 0) + \text{diag}(0, 0, B) = \text{diag}(R, G, B), \quad (2)$$

- conjunction

$$\text{diag}(R, G, B) \times \text{diag}(R, 0, 0) = \text{diag}(R, 0, 0), \quad (3)$$

$$\text{diag}(R, G, B) \times \text{diag}(R, G, 0) \times \text{diag}(0, G, B) \times \text{diag}(R, 0, B) = \text{diag}(0, 0, 0), \quad (4)$$

- idempotence property

$$\text{diag}(R, 0, 0) + \text{diag}(R, 0, 0) = \text{diag}(R, 0, 0), \quad (5)$$

$$\text{diag}(0, 0, B) \times \text{diag}(0, 0, B) = \text{diag}(0, 0, B). \quad (6)$$

### 3.3. Basic Optical Logic Framework

The authors of the articles [27,43] proposed optical designs of computing networks based on an optimized architecture, called the base, considering the need for alternative decisions and the minimum median spread of expert assessments or sensory information. It includes the first level of evaluations of three "main" experts; 6 additional, "coordinating experts", placing them two by two in three parallel branches converging in optical summation; the third optical section forms at the output the final decision (assessment) of three "responsible" experts, for example, bearing personal (criminal) liability of one kind or another. The responsibility of the decision determines the need to consider the blocking version of the decision. As an example, let's set the following input estimates from Table 4.

Table 4  
Sample input estimates for the optical-logic worked example

| Nº | Factor (units)           | Assessment       | Quantum |
|----|--------------------------|------------------|---------|
| 1  | Cross wind speed, m/s    | Strong (7–9)     | {R}     |
| 2  | Aircraft type            | Wide (2 engines) | {G}     |
| 3  | Dispatcher qualification | High             | {B}     |

| №  | Factor (units)                         | Assessment       | Quantum |
|----|----------------------------------------|------------------|---------|
| 4  | Snow, cm                               | 2–5              | {M}     |
| 5  | Time of day                            | Dark time of day | {M}     |
| 6  | Flight intensity                       | High             | {Yel}   |
| 7  | General condition                      | Good             | {C}     |
| 8  | Number of aircraft in front of taxiway | 1                | {C}     |
| 9  | General condition of the pilots        | Good             | {C}     |
| 10 | Crew qualification (+2 pilots), h      | 5 000 – 10 000   | {M}     |
| 11 | Visibility, m                          | 700 – 1600       | {M}     |
| 12 | Staffing of the dispatch service       | Fully            | {C}     |

Using matrix equations (1-6), for logical operations defined by the optical base structure (shown in Figure 2) and the given input data represented by the corresponding color values of the light filters, we write down the output sequence of the logical decision. The first logical operation of disjunction is written in the form of the sum of diagonal matrices

$$\text{diag}(R, 0, 0) + \text{diag}(0, G, 0) + \text{diag}(0, 0, B) = \text{diag}(R, G, B).$$

Logical operations in the second section will take the form

$$\text{diag}(R, G, B) \times \text{diag}(R, 0, B) \times \text{diag}(R, 0, B) = \text{diag}(R, 0, B),$$

$$\text{diag}(R, G, B) \times \text{diag}(R, G, 0) \times \text{diag}(0, G, B) = \text{diag}(0, G, 0),$$

$$\text{diag}(R, G, B) \times \text{diag}(0, G, B) \times \text{diag}(0, G, B) = \text{diag}(0, G, B).$$

At the output of the second section, a disjunction operation is performed

$$\text{diag}(R, 0, B) + \text{diag}(0, G, 0) + \text{diag}(0, G, B) = \text{diag}(R, G, B).$$

The third section forms the final decision

$$\text{diag}(R, G, B) \times \text{diag}(R, 0, B) \times \text{diag}(R, 0, B) \times \text{diag}(0, G, B) = \text{diag}(0, 0, B).$$

Note that for the combination of estimates for which the output set of section 2 is a confident positive set {B} and the combination of estimates of section 3 includes estimates {Yel}, the light emission is blocked and there is no output decision, i.e. {Blc}:

$$\text{diag}(0, 0, B) \times \text{diag}(R, G, 0) \times \text{diag}(R, G, 0) \times \text{diag}(0, G, B) = \text{diag}(0, 0, 0).$$

A new decision is formed by changing the combination of current estimates of aircraft condition, airport conditions, and environmental parameters.

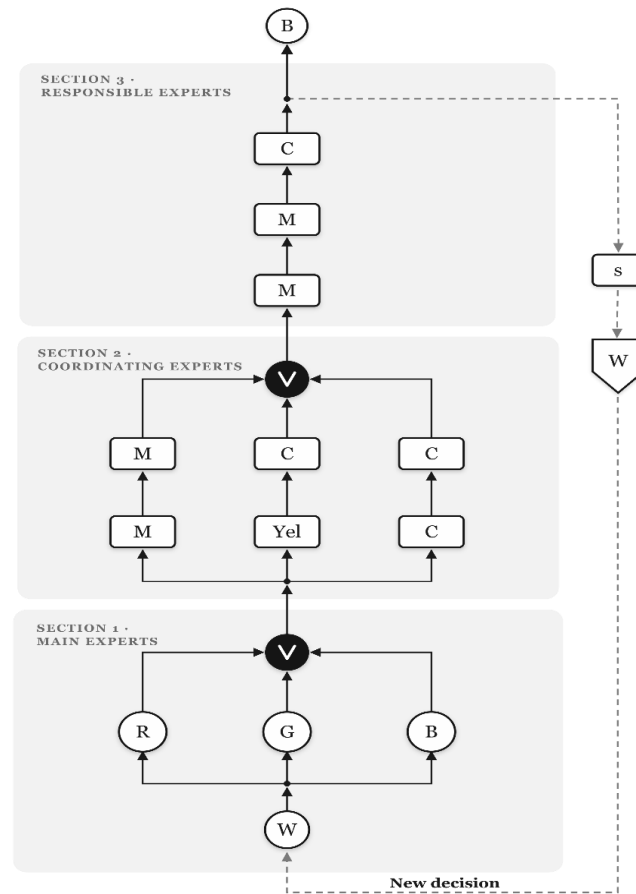


Figure 2: Optical base structure.

#### 4. Modeling Framework for Evaluating the Safety of Complex Transport Processes (Aerospace Case)

Let us consider the formation of a database and the optical structure of logical inference using the example of analyzing the factors influencing the decision-making process of an aircraft pilot during takeoff (AIRBUS 300 aircraft) [4]. We note the allocation of the main sections of the takeoff process in the practical guide: general restrictions on aircraft operation; restrictions on runway operation; restrictions on altitude gain and obstacle clearance; external factors; determination of the maximum takeoff weight; takeoff with reduced thrust or with derated engines. It should be noted that we use safety assessment parameters that change dynamically over time, which are primarily fuzzy and qualitative, i.e., set within certain measurement limits. Naturally, the quantitative parameters of the aircraft should also be determined as accurately as possible and considered in the overall safety assessment. The most important task here is the visualization of output data for the fastest possible perception and response by aircraft pilots. Let us define the main, coordinating and responsible factors (only as a demo) to demonstrate the decision-making model based on the optical logical structure. The main factors (for the two-level optical structure of the type shown in Figure 3), a total of 9, ratings {R}, {G}, {B}): maximum speeds; maximum takeoff weight of the structure; takeoff thrust limitation; takeoff decision speed; takeoff run limitations; minimum and maximum climb gradient; crosswind component; runway condition; takeoff at reduced thrust level or with derated engines. Coordinating factors (total 24, ratings {Yel}, {C}, {M}): g-force limitations; minimum speeds; maximum structural weight without fuel; maximum structural weight during taxi; minimum structural weight; takeoff operating speeds; take-off the angle of flaps; lift-off speed; takeoff climb speed; takeoff speed limitations; speed at which the braking system dissipates the aircraft's kinetic energy; takeoff roll distance available; rejected takeoff distance available; effect of speed on takeoff weight limited by

runway length; turn pattern; straight takeoff obstacle clearance; obstacle clearance during turn; loss of gradient during turn; takeoff cone; effect of altitude on engine pressure; temperature; effect of temperature on aerodynamic characteristics; effect of temperature on engines; visibility; time of day.

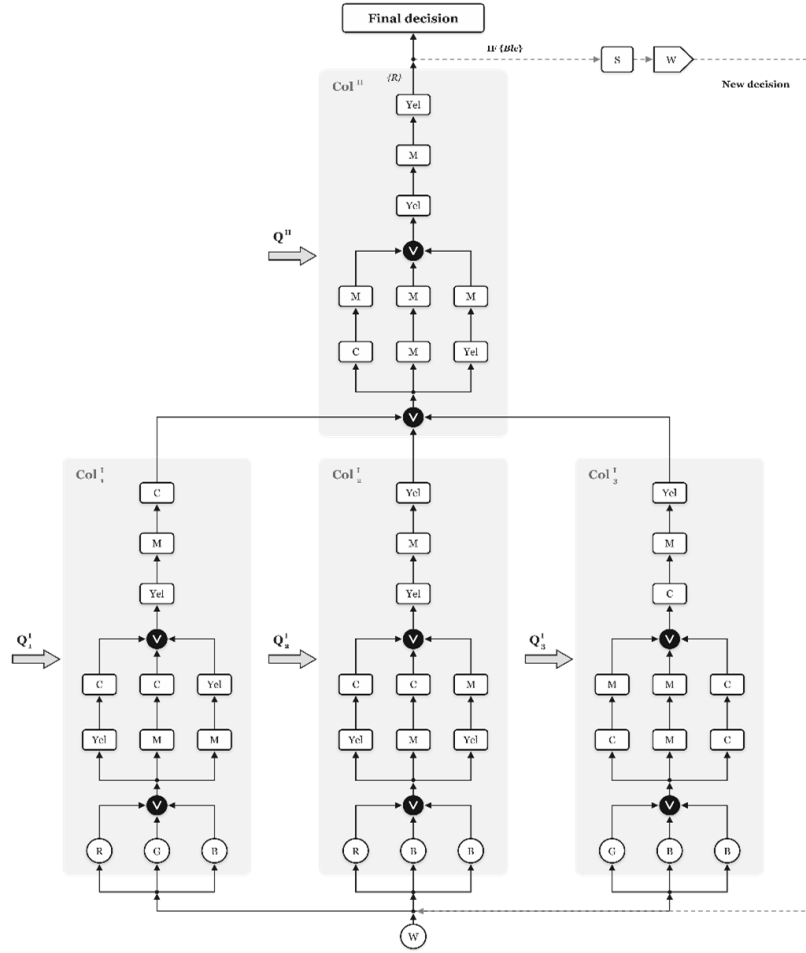


Figure 3: Two-level logical color decision-making networks.

In this way, we softened the severity of the decision, assuming that the pilots would make the final decision. Responsible factors (total 12, ratings {Yel}, {C}, {M}): maximum structure weight during taxiing; stall speed; engine failure speed; exhaust gas temperature limitations; rejected takeoff distance; obstacle clearance height; longitudinal wind component; influence of pressure altitude on aerodynamic characteristics; runway slope; snow (sleet, dry snow, compacted snow); ice (friction coefficient); water (slush). Thus, a fuzzy database of 45 factors (parameters) determining the safety of an aircraft in takeoff mode has been formed. Equations of the form (1-6) ultimately decide the output solution. In its absence, {Blc}, the formation of a request for a new solution considers a possible change in the input data. Synthesis of multicomponent multilevel DSS assumes, depending on the purpose of a specific technological task with a large volume of input fuzzy data, the formation of hierarchically organized structures of various types of logical inference rules and further implementation based on the proposed basic logical optical structures.

## 5. Conclusion

The paper proposes optical computing structures based on the logical transformation of color information quanta. Input information is represented as fuzzy sets defined by the corresponding color quanta, ranked relative to the positive solution. The flexible optical structure allows for implementing various logical inference trajectories, considering the required decision-making tasks.

The proposed approach to forming a DSS for transport processes with large volumes of data is demonstrated on the example of air traffic risk control as one of the most demanding cases. For a separate DSS component assessing the safety of aircraft takeoff (using data from AIRBUS), a database of 45 parameters was formed, and a two-level optical network for decision-making (assessment) during takeoff was proposed. The main advantages of the proposed decision-making structures are: the components perform basic logical operations of disjunction and conjunction, processing large volumes of fuzzy input information without switching computational components; the flexible structure allows for various logical inference trajectories depending on the complexity of the decision-making tasks; the input factors are ranked relative to the positive solution, which orders the inference and makes its result interpretable. Implemented as an optical architecture, these decision structures gain a further set of advantages that are well suited to the demands of transport safety tasks: high processing speed: a light emitter in the femtosecond range provides an information processing rate determined by the speed of light at minimal power consumption; structural parallelism: the color computing networks are parallelized by construction, which supports a virtually unlimited rate of information input; resistance to noise and interference in the input data; direct integration with optical information transmission; immediate visual interpretation of large volumes of heterogeneous output parameters, allowing the operator to recognize quickly which of them approach a dangerous range. The principles proposed for constructing this class of decision support systems are general and extend to a broad range of transport processes — on land, at sea, and in the air. Related decision-support approaches have been developed for maritime navigation and ship collision avoidance [5–9, 13, 47], for road transport and vehicle routing under uncertainty, and for air traffic control and crew support [14–16, 24–26]. The color optical computing method underlying the present work has been applied by the authors to the safety of ship navigation [27] and to mobile decision-support platforms based on color information processing [43, 44], which confirms its transferability across transport domains. In the present study, this unified approach to building a DSS for transport processes with large volumes of data is successfully demonstrated on the example of air transportation; the same fuzzy color databases of safety factors and optical inference architecture can be reused for other transport modes characterized by heterogeneous big data and high decision dynamics. Further development of the DSS in the field of air traffic risk control is the expansion of the scope of applicability for pre-flight preparation of aircraft, the distinctive feature of which is sufficient process time and the absence of critical modes, control of a highly dynamic landing process, mainline flight (with sufficient process time, but with the possibility of critical modes), as well as control of highly dynamic processes of intensive aircraft traffic control at airports. In the further development of optical color computing, the primary focus should be on developing experimental samples, creating nanoscale structural computing components, and ensuring their manufacturability.

## Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

## Declaration on Generative AI

The authors have not employed any Generative AI tools.

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