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ESTIMATION OF BAD WEATHER CONDITIONS INFLUENCE ON DIFFERENT PHASES OF FLIGHT USING EXPERT JUDGEMENT METHOD

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Abstract

Purpose: estimation of the influence of five different types of bad weather conditions: fog, wind shear, thunderstorm, icing and snow on the aircraft operations during three stages of flight: takeoff and climb, enroute, descent and landing. Methods: using the significance of influence on the flight operations as the parameter of comparison, bad weather conditions are compared by experts in their questionnaires. With the help of expert judgement method, the experts' group opinions are obtained, coordinated, the significance of calculations criteria and weight coefficients are calculated. Using the results of calculations, the general histogram of weight coefficients for three different stages of flight is built, representing the significance of bad weather conditions influence on aircraft operations. Results: the expert system methodology presented in this work helps to evaluate the impact of weather events on the flight operations and select the appropriate measures of preventing bad weather conditions influence on each stage of flight. Discussion: the derived expert system can be used in airplane operations to evaluate the impact caused by weather, for further improvement of the situational awareness and decision making process of aviation staff with the application of new artificial intelligence technologies.

Keywords: accident; artificial intelligence; bad weather conditions; expert judgement method; machine learning; stages of flight

1. Introduction

Various weather conditions can significantly affect aircraft operations in different ways – from the everyday consideration of wind strength and direction, to the more unusual challenges such as snow or heavy fog. Low cloud, fog and rain may reduce visibility at or around an airport while thunderstorms and lightning can cause serious disruption to flight schedules [1]. Fog has the ability to limit surface visibility to less than 1 km, which can have a significant impact on operations. Snow and blowing snow can greatly affect aircraft on the ground, as well as during climb and descend. Wind shear has a significant effect during take-off and landing due to its effects on control of the aircraft, and it has been a sole or contributing cause of many aviation accidents. In-flight icing is one of the greatest dangers of cold weather flying because it causes airflow disruption that decreases the aircraft's control and performance. Thunderstorms represent some of the worst dangers in aviation as they are one of the most hazardous conditions you can encounter.

The derived estimations in this article could be used in airplane operations to evaluate the impact caused by weather and to implement the new technology and new 'ways' of displaying meteorological information in a way that is consistent with safe and efficient practices [2].

Nowadays International Civil Aviation Organization (ICAO) documents recommend developing Intelligent Expert Systems in aviation to support decision making of operators. The effectiveness of aviation systems and the provision of flight safety depend primarily on the reliability of a human-operator as well as his timely professional decisions. Nowadays in documents of ICAO defined new added approaches for achieving the main goal of ICAO enhancing the effectiveness of global aviation security, and improving the practical and sustainable implementation of preventive aviation security measure. The Global Aviation Security Plan (GASP) identifies five key outcomes for improving effectiveness, such as:

1) enhancing awareness and response of risk;
2) development of security culture and human capability;

3) improving technological resources and foster innovation;
4) improving oversight and quality assurance;
5) increasing cooperation and support between states.

So, the quality of decisions dependences from the development and using of innovative technology in aviation is known nowadays as Artificial Intelligence (AI) [3]. Developing of AI in ANS such as Expert system (ES), Decision Support Systems (DSS), are considering new concepts in aviation need with using modern information technologies and modern courses such as Data Science, Big Data, Data Mining, Multi-Criteria Decision Analysis, Collaboration DM (CDM), Block chain, etc. [4]

The Human Factor still has a significant impact on flight safety – nearly 80% of aviation events are due to the fault of people [5]. The theory of human factor is gradually developing, tested and institutionalized. The evolution of the aviation system in the direction of a complex socio-technical system with gradual changes and additions to the well-known model of the human factor SHEL (1972) to date is given in [6-11].

The authors distinguish stages of the evolution of Human Factor models in aviation, related to the emergence of new components of the aviation system and to improve the diagnosis of Air Navigation System's (ANS's) human-operators (H-O) errors:

1) Professional Skills / Interaction / Errors.
2) Cooperation in team / Interaction in Team / Error Detection.
3) Culture / Safety / Errors Prevention.
4) Safety Management / Safety Balance Models / Minimization of Errors.
5) Collaborative (Joint) Decision-Making (DM) / Data for DM, etc.

For today, the key to ensuring the safety of flights is the problem of the organization of collaborative decision-making (CDM) by all the operational partners – airports, air traffic control services, airlines and ground operators – on the basis of general information on the flight process and ground handling of the aircraft in the airport [10].

The Global Operating Concept for Air Traffic Management (ATM) [12] provides for the provision of a joint (pilot – air traffic controller (ATC)) DM air traffic control unit based on a dialogue between them and real-time information evaluation at all stages of the flight. Coherent, clear interaction between pilot and ATC is most important in emergency in flight. The bad weather conditions influence on different phases of flight. The ATC is responsible for the correctness and timeliness of the information and advice that given to flight crew, so the ATC in such situations is also given a significant role [13, 14]. The main requirement for the ATC when an emergency arises is the constant readiness to provide the necessary assistance to the flight crew, depending on the type of situation, taking into account the air situation and meteorological conditions. One of the factors that greatly complicate the interaction between pilot and ATC is the inadequate knowledge of the flight crew procedures performed in emergency [15].

2. Analysis of the latest research and publications

Data of the National Transportation Safety Board (NTSB) shows, that during the last 10 years 21, 3% aviation accidents happened due to weather conditions, of which 39,1% – in bad weather conditions. The major cause of aviation accidents in bad weather conditions (68%) considered improper and untimely DM by crew of the aircraft [16]. Poor weather conditions still represent the largest component for environmental factors – according to IATA Safety Report for year 2016 bad weather conditions are present in 49 percent of the accidents [17].

The lives of air passengers in the sky and people on the ground depend on the adequate interaction between the pilot and ATC.

According to the statistics of the Aviation Safety Network (ASN) [18], during the second half of the 20th century due to problems in interaction pilot – ATC (language barrier, communicating problems, ATC's interference in the flight crew, wrong ATC instructions / commands, etc.) killed about 2 000 people in aviation accidents.

Thus the following accident statistics with contributory cause of weather is presented in the Aviation Safety Network safety database:

1) 224 occurrences caused by icing (including 133 loss of control, 15 forced landings outside airport, 11 all engine power loss);
2) 132 occurrences caused by low visibility (including 55 Controlled Flight into Terrain (CFIT) – Ground, 26 Controlled Flight into Terrain (CFIT) – Mountain, 9 loss of control);
3) 116 occurrences caused by windshear or downdraft (including 36 loss of control, 18 runway mishaps, 9 heavy landings);

4) 91 occurrences caused by turbulence (including 55 loss of control, 19 wing failures, 11 runway excursions);
5) 26 thunderstorm occurrences (including 20 loss of control, 4 airframe failures, 2 instrumental issues).

In many respects, the World area forecast system (WAFS) and the ICAO direct satellite broadcasts have already made the transition to a seamless and transparent system, which, moreover, is also converging with systems for the exchange of Operational meteorological information (OPMET) messages. The global ATM system will require access to global meteorological information on a far shorter timescale than has been customary in the past. In many cases, virtual "instant" access, including real-time data, will be required.

Such stringent requirements will dictate that as many of the processes as possible, which the systems comprise, must be automated.

The meteorologists' input will be increasingly transferred to the beginning of the processes, even to the extent of transferring knowledge and experience through artificial intelligence to dedicated expert systems [3].

3. Research tasks

The research tasks are:

– to estimate the significance of bad weather conditions influence on the aircraft operations during three stages of flight.

– to build the histograms of weight coefficients for three different stages of flight.

– to define the most influential weather conditions for each stage of flight.

4. The estimation of bad weather conditions influence on different phases of flight using EJM

Expert System is one of type of the Artificial Intelligence (AI) systems. Besides AI technologies can be clustered in the following capabilities, such as Machine Learning (ML); Natural Language Processing (NLP); vision; speech; planning; robotics, decision support system, etc. In AI, an expert system is a computer system that simulates the decision-making ability of a human [19].

Expert systems are designed to solve complex problems by reasoning through bodies of knowledge, represented as if-then rules rather than through procedural code. The first expert systems were created in the 1970s and then proliferated in the 1980s. Expert systems were among the first truly successful forms of AI software. To build an expert system, the Expert Judgement Method (EJM) is used.

Algorithm of Expert Judgment Method is presented on Fig.1.

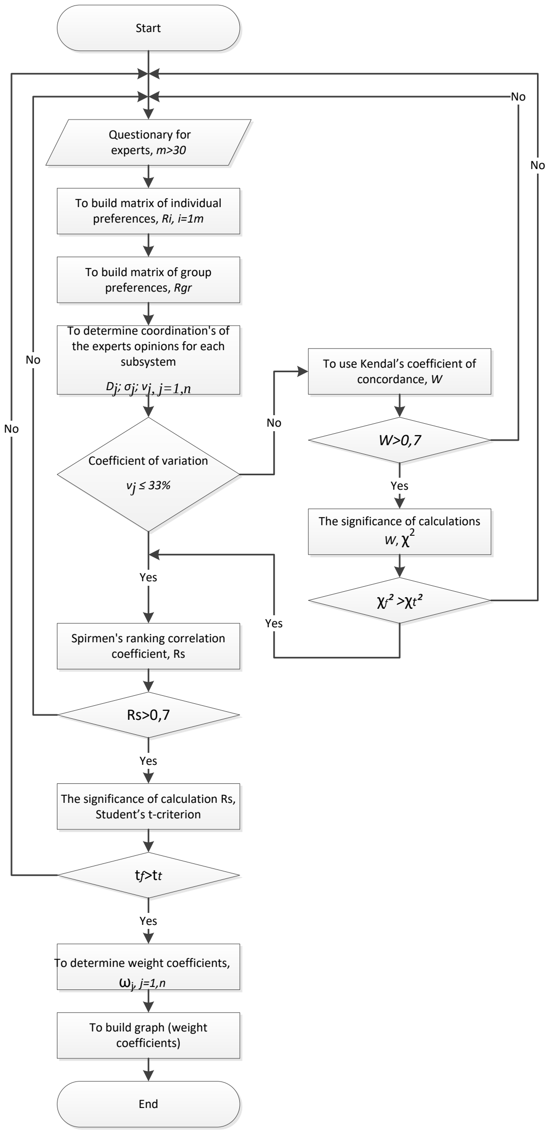

Fig. 1. Using EJM for building Expert Systems

Main steps of building Expert system:

1. System analysis of complex system.
2. Decomposition complex systems on subsystems:
   a. Definition subsystems for expert estimation of their significance and description of the characteristics of subsystems;
   b. Definition of criteria estimation (3-5 criteria) and description of criteria features;

c. Estimation of subsystems using Expert Judgment Method (EJM) by criterion №1 and obtaining weight coefficients of subsystem significance by criterion №1;

d. Analogical calculation for the next criteria.

3. Aggregation subsystems in systems:

a. Additive aggregation of criteria (1):

$$W_k = \sum_{k=1}^{K} w_k f_k \qquad (1)$$

b. Multiplicative aggregation of criteria (2):

$$W_k = f_1^1 f_2^2 f_3^3 \cdot \ldots \cdot f_k^k \ldots \cdot f_K^K \qquad (2)$$

4. Graphical presentation of Expert System.

For example, let's estimate the significance of bad weather conditions influence on the aircraft operations during three stages of flight using EJM:

1) Matrices of individual preferences were obtained after ten experts completed their questionnaires.

2) Matrix of group preferences of expert`s opinions on takeoff/climb; on route; on descend/landing in Table 1. The experts' group opinion for each condition was obtained according to the values of experts individual preferences by the formula (3):

$$\mathrm{R_{grj}} = \frac{\sum_{i=1}^{m} Ri}{m} . \qquad (3)$$

Table 1

Expert's group opinion on takeoff/climb; on route; on descend/landing in flight

Rgr	Fog	Wind shear	Thunder storm	Icing	Snow
takeoff/ climb	2,1	2,15	3,55	4,7	2,5
enroute	4,7	2,35	1,25	2,55	4,15
descend/ landing	3,6	1,95	4,25	2,8	2,4

3) Determination the coordination of expert's opinions (Table 2):

Dispersion for each factor is calculated by the formula (4):

$$Dj = \frac{\sum_{i=1}^{m} \left(R_{grj} - R_i\right)^2}{m-1} \qquad (4)$$

Square deviation is calculated by the formula (5):

$$\sigma_j = \sqrt{D_j} \qquad (5)$$

Coefficient of the variation for each factor is calculated by the formula (6):

$$\nu_j = \frac{\sigma_j}{R_{grj}} \bullet 100\% \qquad (6)$$

If coefficient of variation is $\nu_j < 33\%$ - opinion of the experts is coordinated.

If coefficient of variation is $\nu_j > 33\%$ - opinion of the experts isn't coordinated.

Table 2

Coordination of expert's opinions

ν, %	Fog	Wind shear	Thunder storm	Icing	Snow
takeoff/ climb	31,3	38,05	32,15	10,2	59,62
enroute	8,97	26,63	28,28	31,2	13,96
descend/ landing	29,1	78,75	29,99	29,4	42,58

4) Determination of Kendal's coordination coefficient

If coefficient of variation is more than 33%, it is necessary to define Kendal's coordination coefficient by the following formula (7):

$$W = \frac{12S}{m^2(n^3 - n) - m\sum_{j=1}^{m} T_j} , \qquad (7)$$

where $S = \sum (\sum_{i=1}^{m} R_{ij} - \overline{R})^2$, $T_j = \sum (t_i^{\,3} - t_i)$.

Results of Kendal's coordination coefficient are coordinated: W=0.53 (takeoff/climb); W=0.96 (enroute); W=0.36 (descend/landing).

5) Determination of correlation coefficient of Spirman, R_s

With the help of rating correlation coefficient R_s (Spirman correlation coefficient) the opinion of the group of experts and expert №1 are compared by the formula (8):

$$r_{s_i} = 1 - \frac{6\sum_{i=1}^{n} (x_i - y_i)^2}{n(n^2 - 1)} . \qquad (8)$$

Results of correlation coefficient of Spirman, R_s are coordinated: R_s =0.97 (takeoff/climb); R_s =0.99 (enroute); R_s =0.91 (descend/landing).

6) Determination of significance of calculations, criterion $\chi 2$

$$\chi_{\phi}^{2} = \frac{S}{\frac{1}{2}m(n+1) - \frac{1}{12(n-1)}\sum_{j=1}^{m} T_j}. \qquad (9)$$

For all calculations results are significance, $\chi 2 > 0.5$.

To calculate significance of the calculations of R_s (Spirman's coefficient) the Student's criterion $t_ф$ should be determined by the following formula (10):

$$t_{\phi} = r_s \sqrt{\frac{n-2}{1-r_s^2}} \qquad (10)$$

To compare calculated result $t_ф$ with standard t_s the table of t_s values needs to be used: $t_ф$ = 6.91 (takeoff/climb); $t_ф$ = 12.15 (enroute); $t_ф$ = 3.8 (descend/landing).

7) Determination of weight coefficients

Weight coefficients are defined in Table 3 using the formula (11):

$$\omega_{I} = \frac{C_{I}}{\sum_{I=1}^{n} C_j}, \qquad (11)$$

where $C_o = 1 - \frac{R_{Ij} - 1}{n}$ – estimates;

R_{ij} - rank *j*-procedure for *i* expert.

Table 3

Calculations of weight coefficients on takeoff/climb; on route; on descend/landing in flight

		Fog	Wind shear	Snow	Thunderstorm	Icing
Takeoff / climb	Rank	1	2	3	4	5
	Ci	1	0.8	0.6	0.4	0.2
	wi	0.33	0.267	0.2	0.1333	0.067
	lambda	10	10	10	10	10
	Total load	3.333	2.6666667	2	1.3333333	0.667
Enroute	Rank	5	2	4	1	3
	Ci	0.2	0.8	0.4	1	0.6
	wi	0.067	0.2666667	0.133	0.3333333	0.2
	lambda	10	10	10	10	10
	Total load	0.667	2.6666667	1.333	3.3333333	2
Descend /landing	Rank	4	1	2	5	3
	Ci	0.4	1	0.8	0.2	0.6
	wi	0.13	0.333	0.267	0.0666	0.2
	lambda	10	10	10	10	10
	Total load	1.333	3.333	2.667	0.66666	2

8) Plotting the graph

Using the results of weight coefficients calculations (Table 4), general histogram of three cases (Fig.2) was built, which shows that the biggest influence on flight during:

- takeoff and climb has Fog;
- enroute has Thunderstorm;
- descend and landing has Wind shear;

And for all three stages of flight the most influential is wind shear.

Table 4

Weight coefficients of the biggest influence on flight

Meteorological conditions	w_1	w_2	w_3
Fog	0,33	0,07	0,13
Windshear	0,27	0,27	0,33
Thunderstorm	0,13	0,333	0,07
Icing	0,07	0,2	0,2
Snow	0,2	0,133	0,27

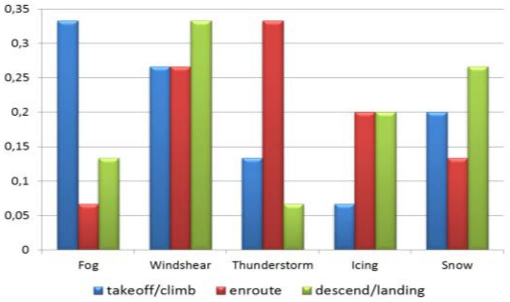

Fig. 2. Weight coefficients of bad weather conditions during different phases of flight

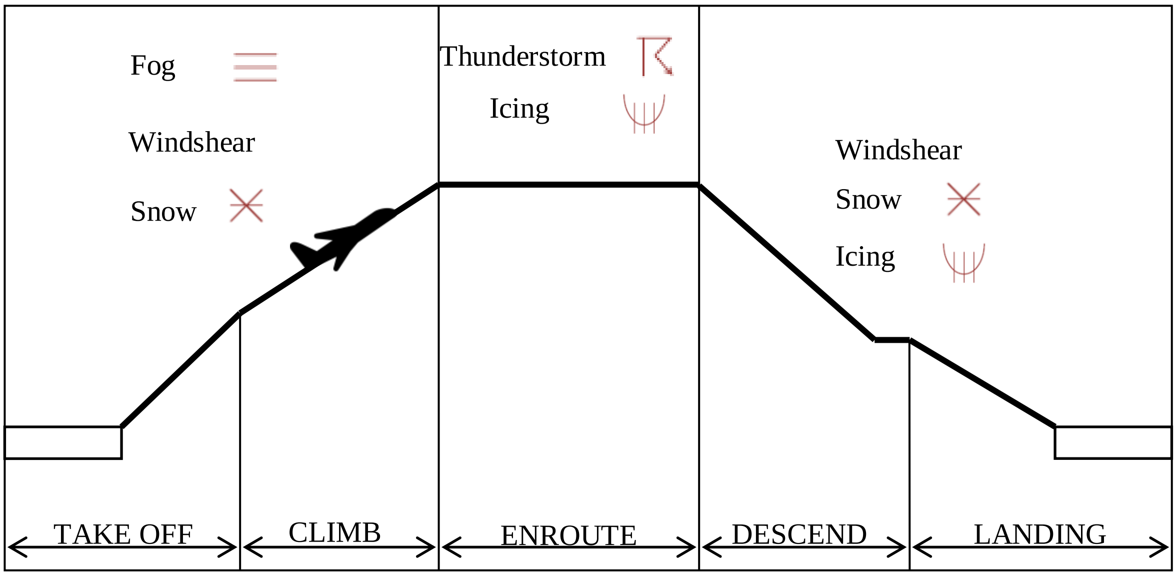

Fig. 3. Relation of bad weather conditions to the different phases of flight

5. Application of new technologies in displaying meteorological information

The US National Oceanic and Atmospheric Administration (NOAA) has tested three machine-learning methods: GBRT (Gradient Boosted Regression Trees), RF (Radio Frequency Machine Learning) and elastic nets, to improve their forecasts. A group of researchers from the NOAA found that “applying AI techniques along with a physical understanding of the environment can significantly improve the prediction skill for multiple types of high-impact weather” [20].

Thus, concerned about the potential for human error, ICAO started looking at smart, cost-effective solutions using AI and Machine Learning technology which users could easily access. The NOTAM Organisational and Recognition Model (NORM) has been developed as the AI technology to help assess the criticality of NOTAMs providing an important piece of information which is essential to personnel concerned with flight operations. ICAO chief of integrated aviation analysis, Marco Merens stated that “now NORM understands the context of each NOTAM and classifies the criticality score from 1 (not significant) to 5 (very critical), just like humans do” [21].

6. Conclusions

Using expert judgement method, the influence of 5 types of bad weather conditions (fog, wind shear, thunderstorm, icing and snow) on the aircraft operations was estimated during three stages of flight:

- Takeoff and climb
- Enroute
- Descend and landing.

To provide an efficient method to capture the impact of weather, using the results of calculations, the general histogram of weight coefficients for three different stages of flight was built which shows that the biggest influence:

- On takeoff and climb has Fog
- On enroute has Thunderstorm
- On descend and landing has Wind shear.

And for all three stages of flight the most influential is wind shear.

To sum up, the methodology presented in this article evaluates the impact of weather events on the flight. These derived estimations could be used for further improvement of the situational awareness and decision making process of pilots through the application of current technologies, and the development and deployment of new artificial intelligence technologies in order to make the aviation system less vulnerable to weather events [2].

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Оцінювання впливу несприятливих погодних умов на різні етапи польоту за допомогою методу експертних оцінок

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Мета: оцінка впливу п'яти різних типів несприятливих погодних умов: туману, зсуву вітру, грози, обмерзання і снігу на експлуатацію повітряних суден протягом трьох етапів польоту: зльоту і набору висоти, польоту по маршруту, зниження і посадки. **Методи:** використовуючи значимість впливу на виконання польоту як параметр порівняння, експерти у своїх анкетах порівняли несприятливі погодні умови. За допомогою методу експертних оцінок отримано та узгоджено узагальнену думку групи експертів, обчислено критерії значимості розрахунків і вагові коефіцієнти. За результатами розрахунків побудовано загальну гістограму вагових коефіцієнтів для трьох різних етапів польоту, що відображає значимість впливу несприятливих погодних умов на експлуатацію повітряних суден. **Результати:** методологія експертної системи, представлена в даній роботі, допомагає оцінити вплив погодних явищ на виконання польоту та вибрати відповідні заходи для запобігання впливу несприятливих погодних умов протягом різних етапів польоту. **Обговорення:** отримана експертна система може бути використана в експлуатації повітряних суден для оцінки впливу погоди, для подальшого вдосконалення ситуаційної обізнаності та процесу прийняття рішень авіаційного персоналу з використанням нових технологій штучного інтелекту.

Ключові слова: аварія; штучний інтелект; несприятливі погодні умови; метод експертних оцінок; машинне навчання; етапи польоту.

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Оценка влияния неблагоприятных погодных условий на различные этапы полета с помощью метода экспертных оценок

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Цель: оценка влияния пяти различных типов неблагоприятных погодных условий: тумана, сдвига ветра, грозы, обледенения и снега на эксплуатацию воздушных судов в течение трех этапов полета: взлета и набора высоты, полета по маршруту, снижения и посадки. **Методы:** используя значимость влияния на выполнение полета в качестве параметра сравнения, эксперты в своих анкетах сравнили неблагоприятные погодные условия. С помощью метода экспертных оценок получено и согласовано обобщенное мнение группы экспертов, вычислено критерии значимости расчетов и весовые коэффициенты. По результатам расчетов построено общую гистограмму весовых коэффициентов для трех различных этапов полета, которая отражает значимость влияния неблагоприятных погодных условий на эксплуатацию воздушных судов. **Результаты:** методология экспертной системы, представленная в данной работе, помогает оценить влияние погодных явлений на выполнение полета и выбрать соответствующие меры для предотвращения воздействия неблагоприятных погодных условий в течение различных этапов полета. **Обсуждение:** полученная экспертная система может быть использована в эксплуатации воздушных судов для оценки влияния погоды, для дальнейшего совершенствования ситуационной осведомленности и процесса принятия решений авиационного персонала с использованием новых технологий искусственного интеллекта.

Ключевые слова: авария; искусственный интеллект; неблагоприятные погодные условия; метод экспертных оценок; машинное обучение; этапы полета.

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