Ministry of Education and Science of Ukraine
National Aviation University

TRANSPORT VEHICLES OPERATION PART VII: THE SIMPLEST RANDOM PROCESS

SELF-STUDY METHOD GUIDE

Part VII

For the Students of the
Field of Study 27 “Transport”
Specialty 275 “Transport Technologies”

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Містять декілька рекомендацій для самостійної роботи щодо застосування знань отриманих при проходженні дисципліни «Експлуатація транспортних засобів», що є необхідним для виконання робіт індивідуального завдання, підготовки до складання заключних видів контролю.

Для студентів 2-го курсу галузі знань 27 «Транспорт», спеціальності 275 «Транспортні технології (на авіаційному транспорті)».

A992 **Transport Vehicles Operation. Part VII : The Simplest Random Process** : Self-Study Method Guide . Part VII / compiler: A. V. Goncharenko. – K. : NAU, 2023. – 61 p.

The **METHOD GUIDE** contains a few recommendations on the Self-Study in regards with the application of the knowledge acquired at the study of the Academic Subject “Transport Vehicles Operation” carrying out, which is indispensable to complete the works of the individual task, get ready for passing the final kinds of the check.

Designed for the 2nd year students of the Field of Study 27 “Transport”, Specialty 275 “Transport Technologies (by Air Transport)”.

CONTENTS

INTRODUCTION

This **METHOD GUIDE ON THE SELF-STUDY** (SS) is contemplated as an ideological continuation of **PART I-VI:**

[263]: **"Transport** Vehicles Operation. Part I : Number of Transport Vehicles : Self-Study Method Guide . Part I . Number of Transport Vehicles . Optimal Choice Dilemma / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2022. – 48 p. https://er.nau.edu.ua/handle/NAU/56234, Method_Guide.pdf."

[275]: **"Transport** Vehicles Operation. Part II: Elementary Supply Chain Optimization : Self-Study Method Guide . Part II / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2023. – 53 p. https://er.nau.edu.ua/handle/NAU/62062, II_TVO_SSG.pdf."

[276]: **"Transport** Vehicles Operation. Part III : Elementary Optimal Supply Speed : Self-Study Method Guide . Part III / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2023. – 53 p. https://er.nau.edu.ua/handle/NAU/62139, III_TVO_SSG.pdf."

[277]: **"Transport** Vehicles Operation. Part IV : Optimal Number of Transport Vehicles : Self-Study Method Guide . Part IV / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2023. – 57 p. https://er.nau.edu.ua/handle/NAU/62141, IV_TVO_SSG.pdf."

[278]: **"Transport** Vehicles Operation. Part V: The Simplest Problem of the Probability of a Choice : Self-Study Method Guide . Part V / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2023. – 54 p. https://er.nau.edu.ua/handle/NAU/62159, V_TVO_SSG.pdf."

[279]: **"Transport** Vehicles Operation. Part VI : The Simplest System Reliability : Self-Study Method Guide . Part VI / compiler: A. V. Goncharenko. – K. : NAU, Electronic Repository. – 2023. – 55 p. https://er.nau.edu.ua/handle/NAU/62201, VI_TVO_SSG.pdf."

in response to the needs of our students in more detailed elaborations concerning the **TRANSPORT VEHICLES OPERATION** (TVO) tasks stated, set, or given for the students' independent work on this **ACADEMIC SUBJECT** for the specified **CALCULATION AND GRAPHIC PAPER** (CGP), possibly used in their further educational works, such as their **TERM PAPERING** (TP), **COURSE PROJECTING** (CP), further **GRADUATION PAPERS** or even **PH.D. STUDIES.** The whole material is split into portions. Each portion is intended to cover a fraction of the probable applications aimed at the **TRANSPORT TECHNOLOGIES** (TT) (by **AIR TRANSPORT** (AT)), particularly dealing with the **TRANSPORTATION ORGANIZATION AND MANAGEMENT ON TRANSPORT** (TOMT) for AT. It means AT management in operation possibly including some **AIRCRAFT** (A/C) technical operation issues in regards with the **AERONAUTICAL ENGINEERING** (AE) **MAINTENANCE** (M/T), as for example, in aviation business.

The presented in the seventh part, **PART VII,** of the **METHOD GUIDE ON THE** SS assignments are dedicated, and a special attention is drawn here, to the general aspects of the SS work for the TVO practical works, individual task, final kinds of the check, future students' prospective research and scientific publications as well as conference reports and presentations.

The scientific component of the SS work is very important. That is why, specifically, the objectives of the **PART VII** material are to help students cope with the challenging problems relating to the studied **ACADEMIC SUBJECT** of TVO on the AT management in operation, for instance, A/C technical operation in regards with the aeronautical engineering M/T as well as the **AIRCRAFT AIRWORTHINESS** support measures. This, **PART VII,** follows [138-140].

The set of the considered issues is based upon the **RECOMMENDED LITERATURE SOURCES** (the list is presented, but not limited to it). The **LIST OF LITERATURE** at the end of the **METHOD GUIDE** is basic (major) and compiled partially not only in the alphabetic order, but mainly with respect to the matter of supposed (assumed) importance.

The **REFERENCES LIST** is selected, set in the order [1-279], does not pretend for completeness, but instead it is aimed at developing the students' abilities of thinking and to analyze, contemplate in the specified directory rather than their abilities to know and memorize. However, these are very significant too. Actually, in the contemporary informative boom world, the needed or required data can be easily retrieved from the internet, found in multiple references, guidance materials [1-23], studies, dictionaries, comprehensive books, publications and scientific papers like [24-279] amongst those monographs [9, 90, 108, 121, 198, 201, 206] etc. The **METHOD GUIDE** is designed for the 2nd year students (**BACHELOR'S DEGREE** contenders) in the Field of Study: 27 "Transport", Specialty: 275 "Transport technologies (by air transport)", Specialization: 05 "Air Transportation Management". The considered studied academic subject of TVO finalizes the previous education in the Field of Study: 27 "Transport", Specialty: 275 "Transport technologies (by air transport)", (**BACHELOR'S DEGREE** contenders); plus of the 1st year students (**BACHELOR'S DEGREE** contenders) in the Field of Study: 27

"Transport", Specialty: 275 "Transport technologies (by air transport)", Specialization: 05 "Air Transportation Management". There are a lot of the planned academic subjects in the **BACHELOR'S** and **MASTER'S DEGREE CURRICULA (CURRICULUMS)** related to the considered studied academic subject of TVO.

This very special seventh part, **PART VII,** of the studied academic subject of TVO is aimed at the **MATHEMATICAL SETTING OF THE PROBLEMS** considered in the CGP on TVO, with the possibilities of the further development to education work, such as, course projects, even up to the graduation papers, **BACHELOR'S** and **MASTER'S DEGREE GRADUATION WORK,** or even Ph.D. studies. Therefore it is strongly suggested for the students to agree their own envisaged course projects, **BACHELOR'S** and **MASTER'S DEGREE GRADUATION WORK THEMES** and prospective research areas with their **SUPERVISORS**.

The scientific portion of the students' SS work might prolong the initiated at the preceding stages of the **BACHELOR'S DEGREE** contending study. It includes the **students' SS research results publication in scientific journals and scientific conferences proceedings**. In the prospect such kinds of the students' activity may lead to a successful defense of the **GRADUATION WORK** or a successful passing the **FINAL STATE EXAMINATION;** as well that may lead to a successful passing of the **UNIVERSITY PH.D.'S DEGREE PROGRAM ENTRANCE EXAMINATION.** The other benefit of the research results publication may be, for example, in the detailed solutions for obtaining the optimal distributions of transportation means: [263, 277], their combinations, optimization of the supply chain links: [275], and supply speeds: [276], probability of a choice: [278], the simplest system's reliability: [279], reliability objective measures allowing assessing the improvements of the A/C functional system M/T process considered in references [138-140].

Herewith it is proposed to continue the search for the detailed solutions for the examples considered in the references of:

[194]: **"Goncharenko A. V.** Multi-optional hybridization for UAV maintenance purposes / A. V. Goncharenko // 2019 IEEE 5th International Conference "Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)" Proceedings. – October, 22-24, 2019, Kyiv, Ukraine. – 2019. – pp. 48-51.**"**

[182]: **"Goncharenko A. V.** Relative Pseudo-Entropy Functions and Variation Model Theoretically Adjusted to an Activity Splitting / A. V. Goncharenko // 2019 9th International Conference on Advanced Computer Information Technologies

(ACIT'2019). – June 5-7, 2019. – Ceske Budejovice, Czech Republic, 2019. – pp. 52-55."

[71]: "**Goncharenko A. V.** Measures for estimating transport vessels operators' subjective preferences uncertainty / A. V. Goncharenko // Scientific Bulletin of Kherson State Maritime Academy. – 2012. – № 1(6). – pp. 59-69."

Completion of CGP is an independent / individual student's work of a creativeness.

The essential sections of the student's report of the CGP completion are:

Introduction;
Literature survey;
Theoretical background;
Major dependencies;
Statistical data;
<u>Student's own contribution;</u>
Derivations;
Findings;
Calculations;
Plotting diagrams;
Analysis;
Discussion;
Conclusion;
References;
Other necessary parts (significant results).

The time required for CGP completion is about 10 academic hours.

The length of the report for the about 10 academic hours completion work is up to 5 pages.

For the **PANDEMIC QUARANTINE PERIOD,** especially **MARTIAL LAW,** it possibly might have the corrections in the **ORDER** of the SS on TVO carrying out.

The general control for the SS on TVO performance is realized (amongst others) through the corresponding **GOOGLE CLASS ROOM.**

Thus, dear students, get down to this challenge to demonstrate your own creativity!

GENERAL PROVISIONS

The principal theoretical provisions can be found out in references [1-23].

1. Planned hours

According to the **TRAINING PROGRAM** on the **ACADEMIC SUBJECT** of the considered TVO and depending upon the particular academic hours specified for the training and study, the entire **SUBJECT** may contain up to many hours.

According with the **TIME TABLE, PROGRAM,** and **CURRICULUM,** regularly approved by the **UNIVERSITY RECTOR'S ORDER,** it figures out like following:

17-19 (optionally 18) weeks of the **SEMESTER WORK,** including some days for the **MODULE TESTS** or the **CGP DEFENSE,** final **GRADED TEST CHECK.**

Thus, it all usually makes a **SEMESTER** weeks **PERIOD.**

Regularly, there might be **2 SHIFTS** that are planned for the **STUDENTS.**

Namely:
The **1ST SHIFT** starts at 8:00;
The **2ND SHIFT** starts at 15:20.

For the **SOPHOMORIC STUDENTS** it is usually the **1ST SHIFT;** and for the not large groups it is just **COMMON LABORATORY CLASSES**, without dividing the groups into **HALVES (SUBGROUPS).**

Therefore, duration is 2 (4) academic hours a week for each **STUDENT** of a group on the day of the **LECTURE DELIVERY** and **LABORATORY CLASS CONDUCTION.** Totally it makes up to 30-40 academic hours of **AUDITORIUM WORK** for the entire considered studied academic subject of TVO. Then, it is plus about up to two thirds of SS (up to 100 academic hours) including up to 30 academic hours for CGP. As whole it may have variations.

As a rule, the information on the **TIME TABLE, PROGRAM,** and **CURRICULUM,** and **TOPICS** are provided at the **AIR TRANSPORTATION MANAGEMENT DEPARTMENT** on the **INFORMATION BOARD (DESK)**; as well as, it can be displaced at the corresponding **GOOGLE CLASS ROOM** and/or the **DEPARTMENT WEBSITE (PAGE), UNIVERSITY REPOSITORY PAGE** etc.

For the **PANDEMIC QUARANTINE PERIOD,** especially **MARTIAL LAW,** the general control for the CGP performance is possible (amongst others) through the corresponding **GOOGLE CLASS ROOM.**

2. Subject content

This step is very important too.

The mentioned above 18 (16) weeks of the Semester study **STUDENTS' WORK** (accordingly with the **TIME TABLE)** are, or might be, subdivided into **COMMON AND INDIVIDUAL TOPICS**:

1.1. Organizational meeting. Instruction on labour protection and fire safety.
1.2. Common aspects of the General Approaches.
1.3. Individual Tasks relations to the chosen research areas.
1.4. Correspondence with the Final Work theme.
1.5. Appropriate methods of the research.
1.6. Mathematical Apparatus for the objectives.
1.7. Mathematical formulation of the conceptual provisions.
1.8. Experimentations.
1.9. Statistical Data processing.
1.10. Analysis of the obtained preliminary results.
1.11. Choice of the corrective methods and ideas.
1.12. Analysis of the use of the corrected methods research results.
1.13. Implementation into the Final Work.
1.14. Prospects of the research results application.
1.15. Publication of the research results.

These **TOPICS** might also be provided at the **AIR TRANSPORTATION MANAGEMENT DEPARTMENT** on the **INFORMATION BOARD (DESK)**; as well as, they can be displaced at the corresponding **GOOGLE CLASS ROOM** and/or **UNIVERSITY REPOSITORY PAGE.**

There is one major document that the student must prepare: CGP **REPORT**. The **REPORT** of the CGP is discussed at the corresponding following **SECTIONS** of this SS **METHOD GUIDE.**

After this **PROGRAM** on CGP completion, and having done and submitted the own **REPORT,** every **STUDENT (AUTHOR)** is supposed attempting to pass the

DEFENSE AND GRADED TEST

The ***DEFENSE*** is going to be discussed further on in this SS **METHOD GUIDE.**

And the best way of the CGP completion is the **SCIENTIFIC PUBLICATION,** which also will be instructed down here in the presented SS **METHOD GUIDE.**

Theoretical material for the CGP tasks is based upon references [1-279]. The idea is traced from the comparatively newest (latest) books [4, 5, 9, 13-17], **NATIONAL PROVISIONS** for aviation business in compliance with the **IATA, EASA,** continental, normative documents, and **ICAO** requirements like in [14]. Some convenient aspects of the subject learning are in the TOMT for AT, TT (by AT), **DIRECTIVES ON TECHNICAL OPERATION,** A/C and AE M/T, referred to in [14].

For the **PANDEMIC QUARANTINE PERIOD,** especially **MARTIAL LAW,** the general control for the CGP performance is possible (amongst others) through the corresponding **GOOGLE CLASS ROOM.**

TRANSPORT VEHICLE TECHNICAL CONDITION AS A RANDOM PROCESS

The principal theoretical provisions can be found out in the references [1-23] and other literature sources and informational resources. Especially [14, 23].

The directions of the CGP work and their completion are reflected in the series of problems offered to be considered, set, and solved.

1. Basic theoretical provisions

First, it is proposed to consider the simplest case of the transport vehicle (aircraft) technical condition (state) transition as a random process of the vehicle functioning. The studied random process will be with the discrete states and the continuous time t.

The graph of the process is shown in Fig. 6.1.

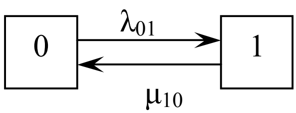

Fig. 6.1 – The simplest system reliability measures prediction scheme

In Fig. 6.1 "0" and "1" are the two possible discrete states of the transport vehicle (aircraft, system) technical condition; λ_{01} and μ_{10} are the failure and restoration rates (failure and restoration intensities), the intensities of the random events flows making the system to transfer (transit, transmit) from one state into the other immediately. The values of the λ_{01} and μ_{10} parameters are deemed to be constant.

The probabilities of the states dynamical properties are determined by the following system of the ordinary differential equations of the first order with the constant coefficients, equations by Erlang, i.e.

$$\left.\begin{aligned}\frac{dP_0(t)}{dt} &= -\lambda_{01}P_0(t)+\mu_{10}P_1(t);\\ \frac{dP_1(t)}{dt} &= \lambda_{01}P_0(t)-\mu_{10}P_1(t);\end{aligned}\right\} \tag{6.1}$$

where $P_0(t)$ and $P_1(t)$ are the probabilities of the corresponding states.

First, it is proposed to sole the simplified to the system (see Fig. 6.1) problem when

$$\mu_{10} = 0\,. \tag{6.2}$$

Equation (6.2) implies that the system transits from the state of "0" into "1" and the reverse transition is impossible. It means that the transport vehicle is cannot be restored (broken, lost, disappeared). That happens, for instance, when an aircraft crash occurs.

Such simplification: (6.2), in the system functioning consideration, in turn, modifies (also simplifies) the system of (6.1), i.e.

$$\left.\begin{aligned}\frac{dP_0(t)}{dt} &= -\lambda_{01}P_0(t);\\ \frac{dP_1(t)}{dt} &= \lambda_{01}P_0(t).\end{aligned}\right\} \tag{6.3}$$

The system of (6.3) can be easily solved starting from the first equation. Splitting variables

$$\frac{dP_0(t)}{P_0(t)} = -\lambda_{01}dt\,. \tag{6.4}$$

Integration of (6.4) yields

$$\ln P_0(t) = -\lambda_{01}t + \ln C\,, \tag{6.5}$$

where $\ln C$ is the logarithm of the constant of integration, the constant can be found from the initial conditions.

From (6.5)

$$P_0(t) = Ce^{-\lambda_{01}t}. \qquad (6.6)$$

Using the initial conditions of

$$P_0(t_0 = 0) = P_0\big|_{t_0=0} = 1, \qquad (6.7)$$

where $t_0 = 0$ is the initial time; one can obtain from (6.6)

$$1 = C. \qquad (6.8)$$

Finally,

$$P_0(t) = e^{-\lambda_{01}t}. \qquad (6.9)$$

The formula of (6.9) has already appeared at the reliability investigations above: (5.21). The only difference is that at the preceding considerations of the previous problem, the probability dealt with the reliability of an element and herewith it relates to the system's state conditions.

As to the second equation of the system of (6.3), now it becomes

$$\frac{dP_1(t)}{dt} = \lambda_{01}e^{-\lambda_{01}t}. \qquad (6.10)$$

Integration of (6.10) yields

$$P_1(t) = -e^{-\lambda_{01}t} + C_1, \qquad (6.11)$$

where C_1 is also a constant of integration that can be determined from the initial conditions of (6.7).

Indeed, the normalizing condition predetermines that

$$P_1(t) = 1 - P_0(t) \qquad (6.12)$$

at any moment of time, therefore,

$$P_1\big|_{t_0=0} = 1 - P_0\big|_{t_0=0} = 0 . \tag{6.13}$$

Applying initial condition of (6.13) to (6.11)

$$1 = C_1 . \tag{6.14}$$

Final solution is

$$P_1(t) = 1 - e^{-\lambda_{01} t} . \tag{6.15}$$

In fact, solution (6.15) follows directly from the solution of (6.9) with the usage of the normalizing condition of (6.12).

2. Initial system solution

Now, getting down back to the initial system of (6.1), see Fig. 6.1.

$$\frac{dP_0(t)}{dt} = -\lambda_{01} P_0(t) + \mu_{10}\left[1 - P_0(t)\right]. \tag{6.16}$$

$$\frac{dP_0(t)}{dt} = \mu_{10} - (\lambda_{01} + \mu_{10}) P_0(t). \tag{6.17}$$

In order to split variables in (6.17), it is proposed to make the change of the variable, i.e.

$$\mu_{10} - (\lambda_{01} + \mu_{10}) P_0(t) = x\,. \tag{6.18}$$

Differentiating (6.18), it can be obtained

$$dP_0(t) = -\frac{dx}{\lambda_{01} + \mu_{10}}\,. \tag{6.19}$$

Substituting (6.18) and (6.19) for their values into (6.17), one will get

$$\frac{dx}{x} = -(\lambda_{01} + \mu_{10})dt\,. \tag{6.20}$$

Then integrating (6.20)

$$\ln x = -(\lambda_{01} + \mu_{10})t + \ln C_2\,, \tag{6.21}$$

where $\ln C_2$ is one more logarithm of the constant of integration.

Expressing the new variable from (6.21)

$$x = C_2 e^{-(\lambda_{01}+\mu_{10})t}\,. \tag{6.22}$$

Then, turning back to the initial variable via (6.18)

$$\mu_{10} - (\lambda_{01} + \mu_{10}) P_0(t) = C_2 e^{-(\lambda_{01} + \mu_{10})t} . \tag{6.23}$$

$$P_0(t) = -C_2 \frac{e^{-(\lambda_{01} + \mu_{10})t}}{\lambda_{01} + \mu_{10}} + \frac{\mu_{10}}{\lambda_{01} + \mu_{10}} . \tag{6.24}$$

Initial condition (6.7) allows obtaining from (6.24)

$$-\lambda_{01} = C_2 . \tag{6.25}$$

Finally, for (6.24)

$$P_0(t) = \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} e^{-(\lambda_{01} + \mu_{10})t} + \frac{\mu_{10}}{\lambda_{01} + \mu_{10}} . \tag{6.26}$$

For the second equation of (6.1)

$$\frac{dP_1(t)}{dt} = \lambda_{01}[1 - P_1(t)] - \mu_{10} P_1(t). \tag{6.27}$$

Through the approach of (6.16)-(6.26)

$$\frac{dP_1(t)}{dt} = \lambda_{01} - (\lambda_{01} + \mu_{10}) P_1(t). \tag{6.28}$$

$$y = \lambda_{01} - (\lambda_{01} + \mu_{10}) P_1(t). \tag{6.29}$$

$$\frac{dy}{-(\lambda_{01} + \mu_{10})} = dP_1(t). \tag{6.30}$$

$$\frac{dy}{y} = -(\lambda_{01} + \mu_{10}) dt . \tag{6.31}$$

$$\ln y = -(\lambda_{01} + \mu_{10})t + \ln C_3 . \quad (6.32)$$

$$y = C_3 e^{-(\lambda_{01}+\mu_{10})t} . \quad (6.33)$$

$$\lambda_{01} = C_3 . \quad (6.34)$$

$$\lambda_{01} - (\lambda_{01} + \mu_{10})P_1(t) = \lambda_{01} e^{-(\lambda_{01}+\mu_{10})t} . \quad (6.35)$$

$$P_1(t) = \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}}\left[1 - e^{-(\lambda_{01}+\mu_{10})t}\right]. \quad (6.36)$$

The sum of (6.26) and (6.36)

$$P_0(t) + P_1(t) = \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} e^{-(\lambda_{01}+\mu_{10})t} + \frac{\mu_{10}}{\lambda_{01} + \mu_{10}} + \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}}\left[1 - e^{-(\lambda_{01}+\mu_{10})t}\right]. \quad (6.37)$$

$$P_0(t) + P_1(t) = \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} e^{-(\lambda_{01}+\mu_{10})t} + \frac{\mu_{10}}{\lambda_{01} + \mu_{10}} + \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} - \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} e^{-(\lambda_{01}+\mu_{10})t} . \quad (6.38)$$

$$P_0(t) + P_1(t) = \frac{\mu_{10}}{\lambda_{01} + \mu_{10}} + \frac{\lambda_{01}}{\lambda_{01} + \mu_{10}} = 1 . \quad (6.39)$$

Random processes graphs makes it possible to consider more complicated sets of states that the simplest shown in Fig. 6.1. Surely, their solutions are more complicated as well.

3. Consideration of a damaged state

For the case that takes into account a damaged state preceding the state of the failure, it is recommended a graph portrayed in Fig. 6.2.

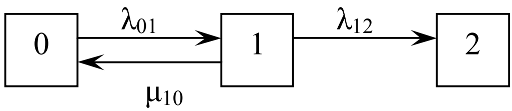

Fig. 6.2 – The system states graph envisaging a damaged state prior to the failure

In Fig. 6.2 “0” and “1” are the possible discrete states of the transport vehicle (aircraft, system) technical condition, up state (normal): “0”, and not failure (but damaged, not normal is such sense): “1”, the system can be restored from “1” to “0”; “2” is the real failure (the state without exit).

That takes place, for example, when an aircraft performs: a normal flight: “0”, is damaged: “1”, and there might an air-crash happen: “2”.

The system by Erlang is

$$\left.\begin{aligned} \frac{dP_0(t)}{dt} &= -\lambda_{01}P_0(t)+\mu_{10}P_1(t); \\ \frac{dP_1(t)}{dt} &= \lambda_{01}P_0(t)-(\lambda_{12}+\mu_{10})P_1(t); \\ \frac{dP_2(t)}{dt} &= \lambda_{12}P_1(t). \end{aligned}\right\} \qquad (6.40)$$

There are a few methods of solving the system of (6.40). One of them is to transform the system (6.40) into the third order differential equation of just one unknown function [23, Chapter XIII, § 29, pp. 103-107, (1)-(10)]. Then, the other way, it is possible to use the characteristic equation [140, p. 24, [38, Chapter XIII, § 30, pp. 108-110, (1)-(6)]; 23] for system (6.40). The other approach is with the *Laplace transformations* in the *operational calculus* [140, p. 25, [38, Chapter XIX, pp. 400-432]; 23].

Anyway, these methods are not easy, of course.

However, using the normalizing condition comparable to (6.12)

$$P_1(t) = 1 - P_0(t) - P_2(t), \tag{6.41}$$

one can derive for the first derivative of the first equation of (6.40) with respect to time: t, the second derivative of $P_0(t)$,

$$\frac{d^2 P_0(t)}{dt^2} = -\lambda_{01} \frac{dP_0(t)}{dt} + \mu_{10}\left[-\frac{dP_0(t)}{dt} - \frac{dP_2(t)}{dt}\right]. \tag{6.42}$$

Applying the third equation of (6.40)

$$\frac{d^2 P_0(t)}{dt^2} = -\lambda_{01} \frac{dP_0(t)}{dt} + \mu_{10}\left[-\frac{dP_0(t)}{dt} - \lambda_{12} P_1(t)\right]. \tag{6.43}$$

And from the first equation of (6.40)

$$\frac{\dfrac{dP_0(t)}{dt} + \lambda_{01} P_0(t)}{\mu_{10}} = P_1(t). \tag{6.44}$$

Substituting (6.44) for its value into (6.43)

$$\frac{d^2 P_0(t)}{dt^2} = -\lambda_{01} \frac{dP_0(t)}{dt} + \mu_{10}\left[-\frac{dP_0(t)}{dt} - \lambda_{12} \frac{\dfrac{dP_0(t)}{dt} + \lambda_{01} P_0(t)}{\mu_{10}}\right]. \tag{6.45}$$

Obvious transformations of (6.45) lead to

$$\frac{d^2 P_0(t)}{dt^2} = -(\lambda_{01} + \mu_{10} + \lambda_{12}) \frac{dP_0(t)}{dt} - \lambda_{12}\lambda_{01} P_0(t). \tag{6.46}$$

In a shorter (more compact) notation, the equation of (6.46) will acquire the view of

$$\ddot{P}_0 + (\lambda_{01} + \mu_{10} + \lambda_{12})\dot{P}_0 + \lambda_{12}\lambda_{01}P_0 = 0 . \qquad (6.47)$$

It is obtained the ordinary linear homogeneous (uniform) differential equation of the second order whith the constant coefficients, likewise described in [23, Chapter XIII, § 22, pp. 79,80, (1), (2)]. The sought solution is supposed to be found in the view, and with the help of

$$P_0 = e^{kt} , \qquad \dot{P}_0 = ke^{kt} , \qquad \ddot{P}_0 = k^2 e^{kt} . \qquad (6.48)$$

The characteristic equation for (6.47) is

$$k^2 e^{kt} + k(\lambda_{01} + \mu_{10} + \lambda_{12})e^{kt} + \lambda_{12}\lambda_{01}e^{kt} = 0 . \qquad (6.49)$$

Canceling for $e^{kt} \neq 0$

$$k^2 + k(\lambda_{01} + \mu_{10} + \lambda_{12}) + \lambda_{12}\lambda_{01} = 0 . \qquad (6.50)$$

The roots of (6.50) are

$$k_{1,2} = \frac{-(\lambda_{01} + \mu_{10} + \lambda_{12}) \pm \sqrt{(\lambda_{01} + \mu_{10} + \lambda_{12})^2 - 4\lambda_{12}\lambda_{01}}}{2} . \qquad (6.51)$$

The shortened notation of (6.51) will be

$$k_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} , \qquad (6.52)$$

where

$$a = 1 , \qquad b = \lambda_{01} + \mu_{10} + \lambda_{12} , \qquad c = \lambda_{12}\lambda_{01} . \qquad (6.53)$$

If the roots of (6.50) are unequal (not equal, non-equal) real numbers (values), the general solution for the first equation of (6.40), $P_0(t)$, in the view of the first equation of (6.48), can be found as a sum of two linearly independent partial solutions (according with the roots (6.52) values), [23, Chapter XIII, § 22, pp. 79,80, (1), (2)].

Indeed, in regards to the mentioned above

$$\frac{e^{k_1 t}}{e^{k_2 t}} = e^{(k_1 - k_2)t} \neq \text{const} . \tag{6.54}$$

Thus, in case (6.54) the exponent functions are linearly independent.

The only case of linear dependence is when

$$\frac{-b + \sqrt{b^2 - 4ac}}{2a} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}, \tag{6.55}$$

$$2\sqrt{b^2 - 4ac} = 0 , \quad b^2 - 4ac = 0 , \quad b^2 = 4ac . \tag{6.56}$$

Therefore, the general solution for $P_0(t)$, in the view of the first equation of (6.48) with the undetermined, so far, constants of C_1 and C_2, will be

$$P_0(t) = C_1 e^{k_1 t} + C_2 e^{k_2 t} . \tag{6.57}$$

From the initial conditions

$$P_0\big|_{t_0 = 0} = 1 = C_1 + C_2 , \qquad 1 - C_1 = C_2 . \tag{6.58}$$

That yields the sought function of the probability of the system up state: “0”, (see Fig. 6.2), i.e.

$$P_0(t) = C_1 e^{k_1 t} + (1 - C_1) e^{k_2 t} = C_1 \left(e^{k_1 t} - e^{k_2 t} \right) + e^{k_2 t} . \tag{6.59}$$

Then, differentiating (6.59) and using the first equation of (6.40) in combination with the obtained solution of (6.59), one can obtain

$$\frac{dP_0(t)}{dt} = C_1\left(k_1 e^{k_1 t} - k_2 e^{k_2 t}\right) + k_2 e^{k_2 t} =$$

$$= -\lambda_{01}\left[C_1\left(e^{k_1 t} - e^{k_2 t}\right) + e^{k_2 t}\right] + \mu_{10} P_1(t). \quad (6.60)$$

Expressing $P_1(t)$ from (6.60) allows having the direct solution for the second function of (6.40), the probability of the system damaged state: "1", (see Fig. 6.2), i.e.

$$\frac{C_1\left(k_1 e^{k_1 t} - k_2 e^{k_2 t}\right) + k_2 e^{k_2 t} + \lambda_{01}\left[C_1\left(e^{k_1 t} - e^{k_2 t}\right) + e^{k_2 t}\right]}{\mu_{10}} = P_1(t). \quad (6.61)$$

Grouping the members with C_1 in (6.61) one can get

$$\frac{C_1\left[k_1 e^{k_1 t} - k_2 e^{k_2 t} + \lambda_{01}\left(e^{k_1 t} - e^{k_2 t}\right)\right] + \left(k_2 + \lambda_{01}\right) e^{k_2 t}}{\mu_{10}} = P_1(t). \quad (6.62)$$

From the initial conditions, accompanying (6.58)

$$P_1(t)\Big|_{t_0=0} = 0. \quad (6.63)$$

Implementing (6.63) in (6.61) or (6.62)

$$C_1\left(k_1 - k_2\right) + k_2 + \lambda_{01}\left[C_1(1-1) + 1\right] = 0. \quad (6.64)$$

From (6.64)

$$C_1 = -\frac{k_2 + \lambda_{01}}{k_1 - k_2}. \quad (6.65)$$

Applying (6.62) with (6.65) for the last equation of (6.40)

$$\frac{dP_2(t)}{dt} = \lambda_{12} \frac{-\frac{k_2+\lambda_{01}}{k_1-k_2}\left[k_1 e^{k_1 t} - k_2 e^{k_2 t} + \lambda_{01}\left(e^{k_1 t} - e^{k_2 t}\right)\right] + \left(k_2+\lambda_{01}\right)e^{k_2 t}}{\mu_{10}} . \tag{6.66}$$

Obvious transformation of (6.66) will bring

$$\frac{dP_2(t)}{dt} = \frac{\lambda_{12}}{\mu_{10}} \left\{ -\frac{k_2+\lambda_{01}}{k_1-k_2}\left[k_1 e^{k_1 t} - k_2 e^{k_2 t} + \lambda_{01}\left(e^{k_1 t} - e^{k_2 t}\right)\right] + \left(k_2+\lambda_{01}\right)e^{k_2 t} \right\} . \tag{6.67}$$

Integration of (6.67) yields

$$P_2(t) = \frac{\lambda_{12}}{\mu_{10}} \left\{ -\frac{k_2+\lambda_{01}}{k_1-k_2}\left[e^{k_1 t} - e^{k_2 t} + \lambda_{01}\left(\frac{e^{k_1 t}}{k_1} - \frac{e^{k_2 t}}{k_2} \right)\right] + \left(1 + \frac{\lambda_{01}}{k_2}\right) e^{k_2 t} \right\} + C , \tag{6.68}$$

where C is the constant of integration.

From (6.68) and the initial conditions: (6.58) and (6.63)

$$P_2(t)\big|_{t_0=0} = 0 . \tag{6.69}$$

Therefore

$$-\frac{\lambda_{12}}{\mu_{10}} \left\{ -\frac{k_2+\lambda_{01}}{k_1-k_2} \lambda_{01} \left(\frac{1}{k_1} - \frac{1}{k_2} \right) + 1 + \frac{\lambda_{01}}{k_2} \right\} = C . \tag{6.70}$$

From (6.1)-(6.70) one can analyze the reliability optimal solutions. It depends upon some parameters. Their values are up to the students.

4. Numerical simulation

The illustration to the graphical representation is based upon the Mathcad calculation platform.

The magnitudes of the values have a certain conventional (some conditional) measurement units (dimensions).

The students are supposed to set the correspondence.

The results of simulation are shown in Fig. 6.3.

The case of (6.40)-(6.70), as the general for all discussed herewith, is calculated based upon the analytical solutions of (6.59), (6.62), and (6.68) with the corresponding constants of integrations.

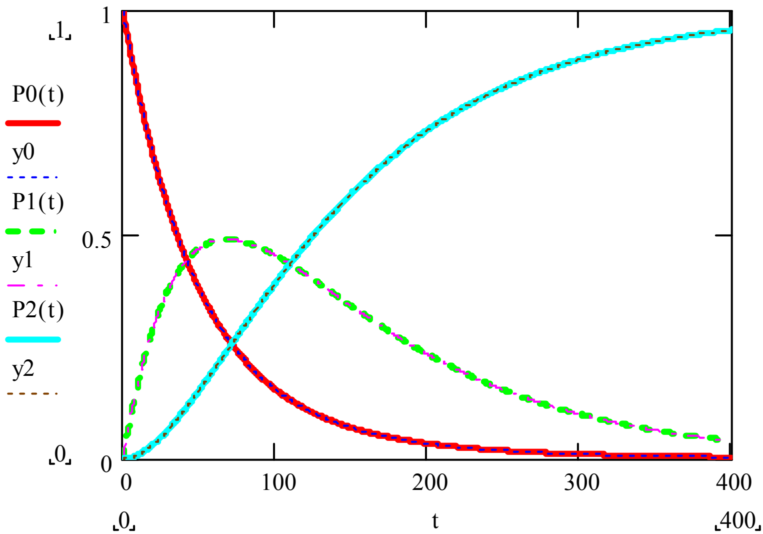

Fig. 6.3 – Probabilities of the system three possible states

In Fig. 6.3 it is shown as well the probabilities calculated by the Solving a First-Order System of Ordinary Differential Equations program in the Mathcad Resource Center: Quick Sheets and Reference Tables: Calculus & Differential Equations section with the examples. Namely: y0 is for $P_0(t)$; y1 is for $P_1(t)$; and y2 is for $P_2(t)$ in correspondence.

It is visible that the mentioned dependencies (solutions) coincide for both analytical (6.59), (6.62), and (6.68) and numerical solutions.

Partial cases from Fig. 6.2 are simulated by appointing the zero values to the specified intensities.

For instance, if

$$\lambda_{12} = 0, \tag{6.71}$$

it gives the Fig. 6.1 case (see Fig. 6.2 as well).

The results are illustrated in Fig. 6.4.

The curves of $P02(t)$ and $P12(t)$ are plotted by calculation of (6.26) and (6.36). They coincide with the partial solutions of y0 and $P_0(t)$, (6.59); y1 and $P_1(t)$, (6.62); applying (6.71).

Whereas y2 and $P_2(t)$, (6.62), are identical zero because of (6.71).

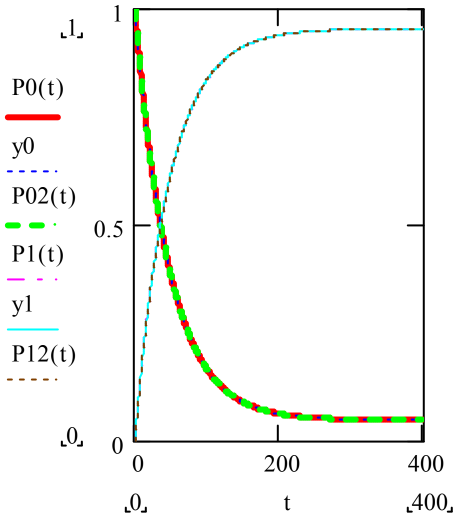

Fig. 6.4 – Probabilities of the system two possible states

The approach (6.1)-(6.71) allows researching the influence of other parameters.

There are some developments of the problem; in the number of the system's possible states, maximal probabilities values optimization, random processes optimization, also in the number of the “good” and “bad” aircraft, different aircraft fleets varying in the aircraft numbers, aircraft types, trajectories, distances, speeds, other random (stochastic, probability) values, cost and other economical issues, dynamics, subject to additional conditions or constraints and so on.

It is possible to plot three-dimensional surfaces and graphically find solutions upon them.

REPORT PREPARATION

The CGP stages are aimed at the effective CGP time management and results estimation control in the field of TOMT for AT, TT (by AT), A/C and AE M/T.

The best way is when it leads to the **SCIENTIFIC FORMALIZATION** of the **RESEARCHED MATTER.** For this purpose the **SCIENTIFIC PUBLICATIONS** suit the best.

The CGP **REPORT** is usually prepared in accordance with the **REPORT TEMPLATE.** As a rule it is provided at the corresponding **GOOGLE CLASS ROOM** and/or **UNIVERSITY REPOSITORY PAGE.**

The **REPORT** must contain the materials connected with CGP, especially with the **REPORT SECTIONS** characteristic, **INTRODUCTION, IMPORTANCE, TOPICS** etc.

The CGP work completion **REPORT** reflects the student's own achievements in acquiring the practical knowledge and skills of work in the **SCIENTIFIC FORMALIZATION** of the **RESEARCHED ISSUES.** For this purpose the **SCIENTIFIC PUBLICATIONS** suit the best.

The **REPORT** must contain the materials connected with CGP, especially with the researched object characteristic, student's own achievements etc.

The **REPORT** must be **SIGNED** (amongst the others) by the **AUTHOR (STUDENT),** with pointing the **NAMES** and **POSITIONS;** also **DATED.**

The **AUTHOR (STUDENT);** should characterize generally the topic; and He/She should emphasize the strong and weak points of the CGP work.

Finally, the **AUTHOR (STUDENT)** should evaluate the CGP work with the own reasonable and own rational **GENERAL ESTIMATION.**

After the CGP work completion (all is **SIGNED, DATED, AND SO ON**) it **(**CGP **REPORT)** must be, along with the CGP author's own **SCIENTIFIC PUBLICATIONS** (if there are any **RELEVANT**), submitted to the **DEPARTMENT COMMISSION** for the **DEFENSE**.

DEFENSE

The principal theoretical provisions can be found out in the references [1-23].

The **DEFENSE** of the CGP **REPORT,** along with the CGP **RELEVANT SCIENTIFIC PUBLICATIONS** (if there are any) on the CGP works completion takes place in the **AIR TRANSPORTATION MANAGEMENT DEPARTMENT COMMISSION** on the corresponding CGP.

The process of the **DEFENSE** is held at the specified period of time.

The **AIR TRANSPORTATION MANAGEMENT DEPARTMENT COMMISSION** on the corresponding CGP is to put the contending **STUDENT** the **FINAL ESTIMATION MARK.**

PUBLICATIONS

The principal theoretical provisions can be found out in the lecture notes of the students who have been attended the lectures, completed practical and laboratory works, finished course projects and homework etc., have some scientific inclinations and in the references [1-279].

For nowadays, it is incredibly important for the students to take part in some scientific activity. Results of such deeds as scientific research must be duly presented to the scientific community. The most popular forms of such presentation are the publications in:

1. Scientific Journals
2. Proceedings of the Scientific Conferences

In any case it is up to the students what and how to do, but relevant **PUBLICATIONS** will definitely help enter the **NEXT STAGE OF EDUCATION** and defend **EDUCATIONAL GRADUATION** and **SCIENTIFIC QUALIFICATION WORKS,** theses, dissertations etc.

Generally speaking the move toward the **PUBLICATIONS** actions may be reduced to a few indispensable steps. Perhaps, the first and apparently the most important is the choice of the scientific supervisor. It has to relate with the general theme of the research and the contender preferences. After finding such field of the creative potential application, it is reasonable to distinguish the specific direction, formulate the problem, propose the solution, and demonstrate verification of the approach and scientific findings.

All the students' findings, including made at the CGP, may be implemented into further students' achievements.

For nowadays the most valuable **PUBLICATIONS** are those indexed in the **SCOPUS** and **WEB OF SCIENCE** **SCIENTIFIC DATABASES.**

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Навчальне видання

ЕКСПЛУАТАЦІЯ ТРАНСПОРТНИХ ЗАСОБІВ

Частина VII

НАЙПРОСТІШИЙ ВИПАДКОВИЙ ПРОЦЕС

Методичні рекомендації
до виконання самостійної роботи
для студентів 2-го курсу галузі знань 27 «Транспорт»,
спеціальності 275 «Транспортні технології
(на авіаційному транспорті)»,
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