ISSN 2079-0023 (print)
ISSN 2410-2857 (online)

УДК 658.511.3

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AN APPROACH TO FORMING DASHBOARDS FOR BUSINESS PROCESSES STATE ANALYSIS

Розглядаються основні особливості панелей індикаторів, їх місце та роль в управлінні бізнес-процесами, основні типи, різноманітні рекомендації з побудови, а також основні інструменти візуалізації. Пропонується підхід до формування панелей індикаторів, призначених для аналізу стану бізнес-процесів. Застосування запропонованого підходу розглядається для аналізу стану бізнес-процесу поставки продукції. В результаті застосування запропонованого підходу був розроблений прототип панелі індикаторів, призначеної для аналізу стану бізнес-процесу поставки продукції.
Ключові слова: управління бізнес-процесами, панель індикаторів, показники ефективності, система шкал, аналіз.

Рассматриваются основные особенности панелей индикаторов, их место и роль в управлении бизнес-процессами, основные типы, различные рекомендации по построению, а также основные инструменты визуализации. Предлагается подход к формированию панелей индикаторов, предназначенных для анализа состояния бизнес-процессов. Применение предложенного подхода рассматривается для анализа состояния бизнес-процесса поставки продукции. В результате применения предложенного подхода был разработан прототип панели индикаторов, предназначенной для анализа состояния бизнес-процесса поставки продукции.
Ключевые слова: управление бизнес-процессами, панель индикаторов, показатели эффективности, система шкал, анализ.

There have been considered basic features of dashboards, their place and role in business process management concept, considered basic dashboards types, considered various recommendations of dashboards construction, and also considered basic visualization tools such as bar and line graphs, pie and scatter charts, bullet graphs and dials. An approach to formation of dashboards, used for the analysis of product supply business process state, has been proposed. Therefore, a set of performance indicators and a related system of scales have been defined. In order to solve the problem of dashboard design which means definition of number, type and place of visualization tools, mathematical models of unbounded and continuous knapsack problems have been applied. As a result of the proposed approach application, a prototype of a dashboard used for the analysis of product supply business process state has been developed.
Keywords: business process management, dashboard, performance indicators, system of scales, analysis.

Introduction. Today Business Process Management (BPM) is a dominate concept of an organizational management. BPM includes a set of methods, techniques, and tools, intended to modeling, execution, and analysis of organization's business processes [1].

Recently, BPM is supported by a set of tools, integrated in order to support business processes life cycle (fig. 1). Hence, business analysts can create business process models which further will be transformed into executable models by IT specialists. Executable process models are deployed in a process engine which is intended to execute processes by delegating tasks to humans and services. Usually the process execution is based on using of Service Oriented Architecture (SOA) concept [2].

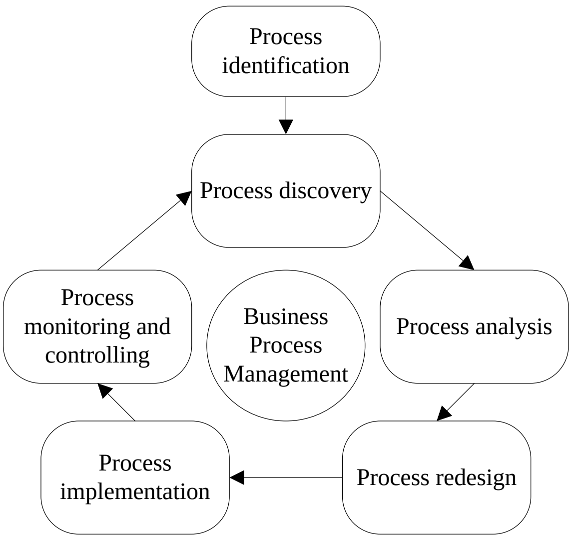

Fig. 1 – BPM lifecycle

An important aspect of BPM lifecycle is continuous analysis of business processes state. It is usually supported by Business Activity Monitoring (BAM) technology which allows performing continuous, literally real-time, business processes monitoring [2].

Therefore analysts define a set of Key Performance Indicators (KPI) and their target values, based on organization's business goals. One of the main features of BAM is presentation of KPIs as dashboards which provide visibility of business performance [2].

Literature review. According to [3], a dashboard is a multilayer application based on business analysis and data integration infrastructure which allows organization performing measurement, monitoring, and business management in more efficient way.

A dashboard allows users tracking organization's performance by comparing actual indicators with indicators defined by a corporate strategy [3].

Difference between dashboards and Balancing Score Cards (BSC) is that dashboards are used to tracking operational business processes, while BSC are used to tracking achievement of analytical and strategic goals [3].

Usually a frequency of data insights depends on business process and how critical data is. Hence there have been defined three types of dashboards: operational, analytical, and strategic (tab. 1) [3, 4].

Table 1 – Dashboard types

Category	Timeline for insights	Update frequency
Strategic	Months or years	Moderate
Operational	Minutes or days	High
Analytical	Minutes to years	Low

Operational level allows users controlling primary business processes: sales, supplies, manufacturing etc. Most of indicators on operational dashboards is repeatedly updating with frequency from several minutes to several hours during the day. Therefore, operational dashboards are focused on monitoring, rather than analysis and management [3].

While the analytical and strategic dashboards are focused on analysis and management, rather than monitoring. The analytical dashboards are intended comparing indicators to plans, forecasts, and results, while the strategic dashboards allow tracking the achievement of the strategic goals and often are based on BSC [3, 4].

Usually, dashboards present KPIs in visual form using diagrams or plain images, for example using images of measuring instruments [3]. Recommendations that allow creating efficient and usable dashboard have been proposed in work [4].

It is necessary to choose data visualization techniques which are clear, easy interpretable, space efficient, attractive, and legible, lead user to the further steps (analysis, decision, action) and allow user performing tasks to achieve its goal (e.g., perform comparisons or monitor performance) [4].

An approach considered in work [5] includes following steps:

- define data and reasons why this data should be measured – it allows interpreting correctly and reusing data in further projects;
- define visualization techniques which allow reducing time that need to understand the data.

Moreover, a dashboard is considered as a system which performing visualization of data which is used for decision making [5].

The most common visualization tools are various graphs and diagrams. Each tool has its own purpose, while some tools are more efficient than others [6, 7]:

- bar graphs;
- line graphs;
- pie charts;
- scatter charts;
- bullet graphs;
- speedometer dials or gauges.

Bar graphs are used to visualize nominal or ordinal scales. Horizontal bar graphs (fig. 2) are considered the most appropriate in a way of information perception [7].

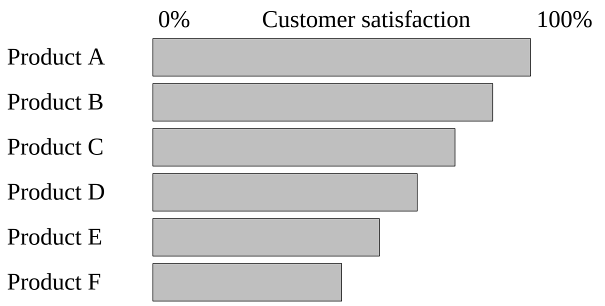

Fig. 2 – Example of a horizontal bar graph

Some bar graphs which are known as grouped bar graphs, allow illustrating more than one measured value, while stacked bar graphs allow illustrating the accumulation effect [6, 7].

Line graphs (fig. 3) are perfect to display time-related data. They are good in illustration of trends, fluctuations, cycles, rates of changes, and allow comparing several sets of time-related data [6].

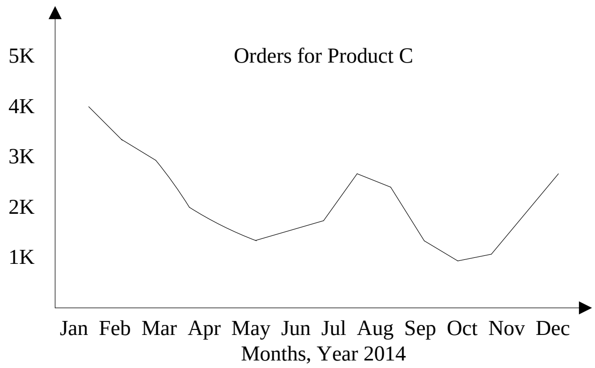

Fig. 3 – Example of a line graph

Pie charts (fig. 4) demonstrate various segments which are presenting data as a percentage of total volume [6]. In most cases bar graphs are better choice, because pie charts are recommended to be used if there are less than six segments. Otherwise they become too complicated for perception of difference between displayed values [7].

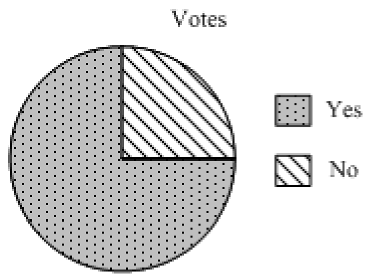

Fig. 4 – Example of a pie chart

To demonstrate the correlation between two datasets, and also illustrate the strength and direction of this relationship, scatter charts are used (fig. 5) [6].

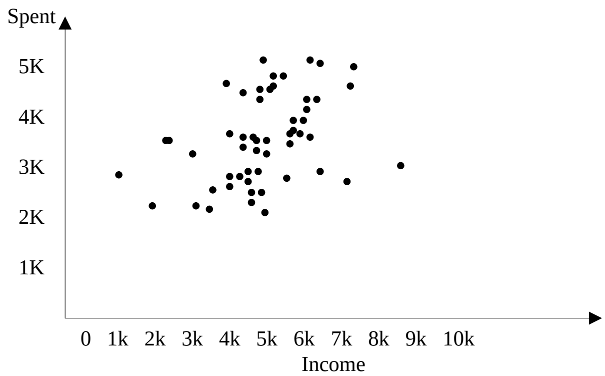

Fig. 5 – Example of a scatter chart

Despite of a huge popularity of speedometer dials (fig. 6) in various KPI reports and dashboards, in most cases their usage isn’t appropriate. Unlike the car speed, KPIs are more static and don’t increase or decrease continuously in time.

Besides, speedometer dials aren't space efficient and can obstruct the indicators comparison [6]. Authors of works [6, 7] recommend avoiding usage of speedometer dials whenever it's possible.

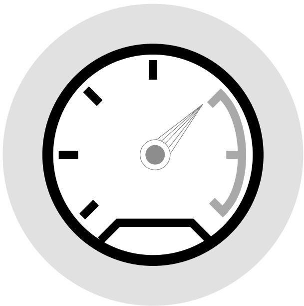

Fig. 6 – Example of a speedometer dial

Bullet graphs (fig. 7) are more appropriate for dashboards than speedometer dials. They have been developed by visualization expert Stephen Few. Bullet graphs are more space efficient, which makes them simple for perception and comparison to other tools [6, 7].

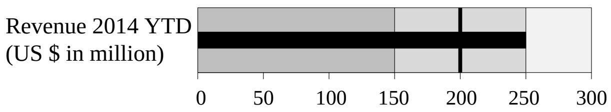

Fig. 7 – Example of a bullet graph

Two main principles which define the choice of one or another visualization tool have been proposed in work [7]:

- it has to be the best tool for displaying the data of a certain type on a dashboard;
- it has to be capable of serving its purpose even when its size is changed in order to place it into the small space.

Besides the recommendations, work [7] considers the basic mistakes of dashboards construction. Errors associated with the choice of inappropriate visualization tools are the most common.

According to the research [8], the prevalence and value for each of the considered visualization tools has been defined (tab. 2).

Table 2 – Prevalence and value of visualization tools

Visualization tools	Prevalence, %	Value, %
Bar graphs	55	53
Line graphs	38	46
Pie charts	8	10
Scatter charts	3	23
Bullet graphs	20	25
Speedometer dials	5	12

Hence, the most prevalent and informative visualization tools used to create dashboards are bar graphs, line graphs, and bullet graphs [8].

Another research [4] also notes that bar graphs, line graphs, and bullet graphs are the most efficient visualization tools which are appropriate for a quick comparison.

Besides the using of efficient visualization tools, it's necessary to use a color codes to draw user's attention to the KPIs values [4, 5, 7]:

- red code illustrates the serious divergence of actual and target values of KPIs and hence necessity of immediate actions;
- green code shows good performance;
- yellow code could be used to display that no actions are required.

Development of the efficient and usable dashboards is necessary to support the analysis of business processes state according to the BPM lifecycle [1, 2].

According to the BPM concept, dashboards should provide users real-time data, using measuring tools that are easy to use and perception [9].

Besides KPIs which are used to measure business processes are often grouped into categories of quality, time, flexibility, and cost [10]. It's recommended to use considered visualization tools, such as bar graphs, line graphs etc, to illustrate KPIs values of each category [4, 8].

Four types of KPIs with recommended visualization tools have been considered according to the best practices of dashboards design [11]:

- quantitative – bar graphs;
- directional – line graphs, scatter charts;
- actionable – bullet graphs, speedometer dials;
- distribution – pie charts.

Most of BPM systems provide business process monitoring. They allow obtaining data about business process events. BAM tools allow using simulation techniques or Business Intelligence (BI) to extract patterns from data and display information using real-time dashboards [12].

Real-time Event Processing which is base of BAM concept allows timely processing and reacting to critical KPIs changes [10].

According to a research [12], organizations are interested in application of business processes monitoring. The interest which declined in 2013 began to grow again (fig. 8). Of the 116 organizations that participated in the survey in 2016, 20 organizations are already using and another 15 are planning to use dashboards to monitor business process performance.

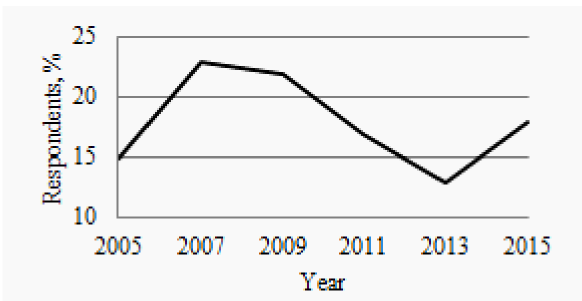

Fig. 8 – Organizations interested in process monitoring

Therefore, the problem of the dashboard design, which is intended for the analysis of organizational business processes state, becomes relevant. It requires placing various visualization tools in a small space, while keeping it accessible and easy to understand.

Formulation of the problem. The research goal is to develop an approach to forming dashboards which are intended to analyze business processes state.

To accomplish the goal, the following tasks should be considered:

- to choose a business process which state is supposed to be analyzed, and its KPIs;
- to define a system of scales that will be used to measure the KPIs in order to analyze the business process state;
- to choose the mathematical models intended to solve the problem of the dashboard design, which allow defining the number, types and placement of the visualization tools.

An approach to forming dashboards for business processes state analysis. One of the primary organizational business processes which requires continuous monitoring and enhancement, is the products supply process. There have been accumulated a lot of experience in order to solve such problems, which has to be analyzed and applied considering features of the specific enterprise. Using of reference models is one of such approaches [13].

Today SCOR (Supply-Chain Operations Reference) is an international inter-industrial standard of supply chains planning and management. It defines three levels of processes and related KPIs (fig. 9). First level is used for diagnostics of the supply chain state. Second level includes indicators are used to diagnosis of the first level's processes. Third level includes indicators are used to diagnosis of the second level's processes respectively. Analysis of indicators through these three levels allows defining business processes that have to be considered more detailed [13, 14].

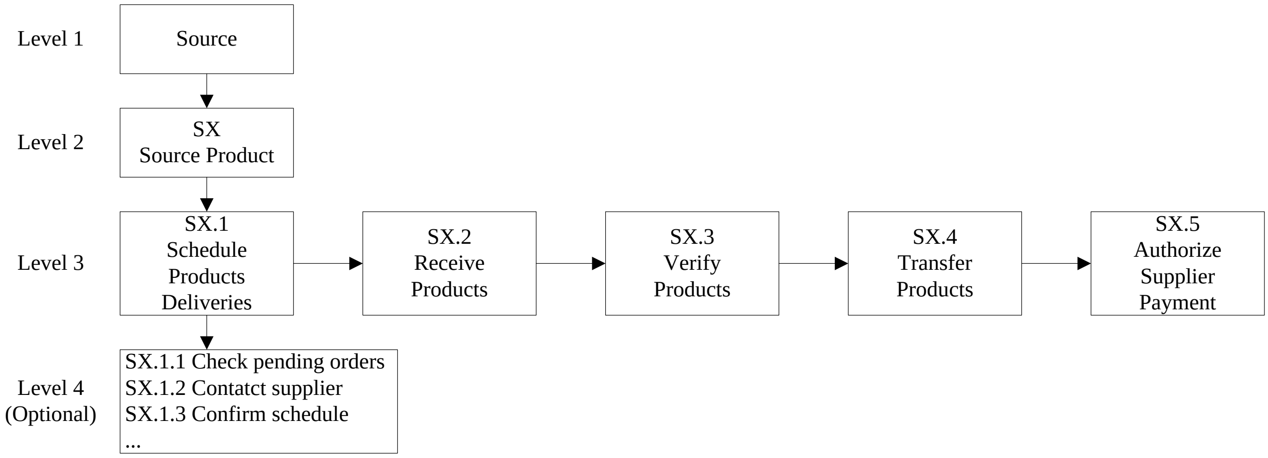

Fig. 9 – Supply process according to the SCOR model

According to the SCOR model, the products supply process is measured by following second-level KPIs [13, 14]:

- cost to supply CtS;
- supply cycle time SCT;
- percentage of supplies delivered in full $\mathrm{OSF}_{\%}$;
- percentage of supplies delivered in time $\mathrm{OST}_{\%}$.

Hence, the cost to supply indicator CtS is decomposed to following third-level indicators [13]:

- cost to schedule product deliveries CoSS (about 12 % of CtS);
- cost to receive products CoRS (about 26 % of CtS);
- cost to verify products CoVS (about 10% of CtS);
- cost to transfer products CoTS (about 46% of CtS);
- cost to authorize supplier payment CoASP (about 6% of CtS).

In its turn, supply cycle time SCT is decomposed to following third-level indicators [13]:

- time to schedule product deliveries SSCT;
- time to receive products RSCT;
- time to verify products VSCT;
- time to transfer products TSCT;
- time to authorize supplier payment ASPCT.

Structure of the products supply business process can be changed according to requirements of the specific organization, considering its KPIs [13].

Formally, measurement of the business processes KPIs includes determination of the sign system corresponding to the measured KPIs. Thus, the scale of measure can be defined as a tuple [15]:

$$< \mathrm{KPI}, f, Y >, \quad (1)$$

here $\mathrm{KPI} = \{x_1, x_2, \ldots, x_n, R_x\}$ – the indicator that includes the set of attributes x_i, $i = \overline{1, n}$ with the ratio R_x is determined according to the measurement purposes;

$Y = \{f(x_1), f(x_2), \ldots, f(x_n), R_y\}$ – the system with the ratio R_y which is mapping the KPI to the numerical system corresponding to the measured indicator;

$f(x)$ – the function which is determining correspondence between the KPI and Y.

ISSN 2079-0023 (print)
ISSN 2410-2857 (online)

During the measurement of business process KPI it is necessary to map the attributes $x_i \in X$ and numbers characterizing these attributes.

Types of scales (1) are determined using the set of allowable transformations $x_i \to y_i$, $i = \overline{1,n}$. According to the scales of measurement classification, there are several types of scales [16]:

- nominal;
- ordinal;
- interval and ratio;
- absolute.

To measure the cost to supply CtS and the supply cycle time SCT it's necessary to use ratio scales which are invariant related to the linear transformations [15, 16]:

$$f_{\text{linear}}(x) = a \cdot x,$$
$$\frac{x_1}{x_2} = \frac{f_{\text{linear}}(x_1)}{f_{\text{linear}}(x_2)} = \frac{a \cdot x_1}{a \cdot x_2} = \text{const}, \quad (2)$$

here $x \in Y$ – the scaling values from the definition area Y;

a – the real number, $a > 0$.

To measure the percentage of supplies delivered in full $\mathrm{OSF}_{\%}$ and the percentage of supplies delivered in time $\mathrm{OST}_{\%}$ it's necessary to use absolute scales which are invariant related to the invariant transformations [15, 16]:

$$f_{\text{identic}}(x) = \{e\}, e(x) = x. \quad (3)$$

Thus, the following system of scales will be used to measure KPIs of products supply business process:

$$\begin{aligned} \{&< \mathrm{CtS}, f_{\text{linear}}(x) = a_{\mathrm{CtS}} \cdot x, Y_{\mathrm{CtS}} >, \\ &< \mathrm{SCT}, f_{\text{linear}}(x) = a_{\mathrm{SCT}} \cdot x, Y_{\mathrm{SCT}} >, \\ &< \mathrm{OSF}_{\%}, f_{\text{identic}}(x) = \{e\}, Y_{\mathrm{OSF}_{\%}} >, \\ &< \mathrm{OST}_{\%}, f_{\text{identic}}(x) = \{e\}, Y_{\mathrm{OST}_{\%}} >\}. \end{aligned} \quad (4)$$

For example, the conversion of minutes to hours when measuring the supply cycle time SCT will be performed according to the linear transformation $f_{\text{linear}}(x)$, where the $a_{\mathrm{SCT}} \approx 0{,}0167$. For the measurement of the percentage of supplies delivered in full $\mathrm{OSF}_{\%}$, x are integers (3).

If the measurement of KPIs requires obtaining aggregated information, the average could be calculated for the homogeneous characteristics y_i, $i = \overline{1,n}$, calculated in the same scale of measure [15]:

$$y_{\text{average}} = \frac{1}{n}\sum_{i=1}^{n} y_i. \quad (5)$$

Event Processing allows processing and reacting to the critical changes of KPIs in a timely manner, using the mapping between the $f(x)$ and Y. Each event belongs to the specific process definition (model) and correspondent process instance [10].

To perform continuous monitoring of the KPIs of the products supply process, which is based on the system of scales (4) and Event Processing, it's necessary to design the correspondent dashboard.

As was noted, the main problem of the dashboard design is placing various visualization tools in a small space, while keeping it accessible and easy to understand [7]. The visualization tools considered above should be used to display information on the dashboard. Prevalence and informativeness values have been defined in the study [8] for each of the considered visualization tools.

It has been also recommended to place all the visualization tools used on the dashboard into the space that suites to the size of a single screen [17].

Usually space becomes a deficit resource due to an unavoidable growth of the processed KPIs amount. This problem could be formalized using the Knapsack Problem with the space as the limited resource and informativeness of the visualization tools as the cost [18].

Therefore to solve the dashboard design problem a following mathematical model has been proposed:

$$\begin{gathered} \sum_{i=1}^{n} v_i x_i \to \max, \\ \sum_{i=1}^{n} s_i x_i \le S, \\ x_i \ge 0,\ i = \overline{1,n}, \end{gathered} \quad (8)$$

here n – the number of the visualization tools that could be used to design the dashboard;

S – the percentage of the workspace that could be used to place the visualization tools, $S \in [0,1]$;

s_i – the percentage of the workspace, required to place the i th visualization tool, $s_i \in [0,1]$, $i = \overline{1,n}$;

v_i – the informativeness of the i th visualization tool, $v_i \in [0,1]$, $i = \overline{1,n}$;

x_i – the amount (integer value) of instances of the i th visualization tool that has been chosen to design the dashboard.

Each of the n visualization tools can be picked multiple times in order to design the dashboard.

The problem (8) can be solved as the Unbounded Knapsack Problem using the dynamic programming technique [19].

The informativeness values v_i for each of the considered visualization tool (tab. 3) have been obtained using the results of the study [8].

Table 3 – Value and informativeness of visualization tools

Visualization tools	Value, %	Informativeness, v_i
Bar graphs	53	0,53
Line graphs	46	0,46
Pie charts	10	0,10
Scatter charts	23	0,23
Bullet graphs	25	0,25
Speedometer dials	12	0,12

The values S and s_i should be defined according to a project features and capabilities of the software and devices used to design the dashboard.

The proposed mathematical model (8) is universal and could be used to provide recommendations in order to design the dashboard intended for the analysis of various business processes state.

Approbation of research results. To solve the problem of the dashboard design, which is intended to the analysis of the products supply process state, the second-level KPIs of the SCOR reference model (7) are used.

According to the recommendations [11], the CtS and SCT indicators could be displayed using the following visualization tools:

- bar graph – x_1;
- line graph – x_2.

While the $\mathrm{OSF}_{\%}$ and $\mathrm{OST}_{\%}$ indicators could be displayed using the following visualization tools:

- pie chart – x_3;
- bullet graph – x_4;
- speedometer dial – x_5.

Thus, the proposed model (8) should be completed with the following bounds:

$$\begin{gathered} x_1 + x_2 = 2, \\ x_3 + x_4 + x_5 = 2. \end{gathered} \tag{9}$$

Considering usage of an 80% of the screen space to place the dashboard visualization tools (considering S = 0,8), while the others 10% are using to place the dashboard toolbar, and the s_i values based on the recommendations [4, 6, 7], the solving of the problem (8) with the bounds (9) respectively has given the following results (tab. 4).

Table 4 – Obtained results

i	Visualization tools	Size, s_i	Amount, x_i^*
1	Bar graphs	0,35	1
2	Line graphs	0,25	1
3	Pie charts	0,20	0
4	Bullet graphs	0,10	2
5	Speedometer dials	0,20	0

Thus, the bar graph and line graph could be used to display the CtS and SCT indicators, while the two bullet graphs could be used to display the $\mathrm{OSF}_{\%}$ and $\mathrm{OST}_{\%}$ indicators respectively (fig. 10).

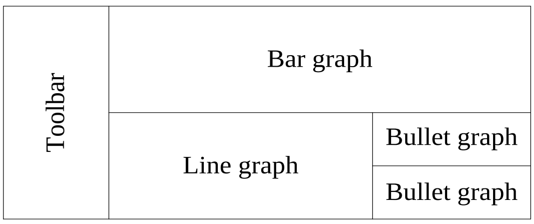

Fig. 10 – Dashboard structure according to the results in tab. 4

Existing BAM and BI solutions [10, 12] provide users with the flexible dashboards customization, including the placing and sizing options.

Therefore, to take the account of these features, the proposed mathematical model (8) should be transformed in the following manner:

$$\begin{gathered} \sum_{i=1}^{n} v_i y_i \to \max, \\ \sum_{i=1}^{n} s_i y_i \le S, \\ 0 \le y_i \le 1,\ i = \overline{1,n}, \end{gathered} \tag{10}$$

here y_i – the amount of instances of the i th visualization tool (real value) that has been chosen to design the dashboard.

This problem (10) can be solved as the Continuous Knapsack Problem using the Greedy algorithm that allows obtaining optimal solution in that case [19].

Thus, the transformed model (10) should be completed with the following bounds:

$$\begin{gathered} y_1 + y_2 > 0, \\ y_3 + y_4 + y_5 > 0. \end{gathered} \tag{11}$$

As a result of solving the problem (10) with the bounds (11) and the same input conditions, the following results have been obtained (tab. 5).

Table 5 – Obtained results for the modified model

i	Visualization tools	Size, s_i	Amount, y_i^*
1	Bar graphs	0,35	1,0
2	Line graphs	0,25	1,0
3	Pie charts	0,20	0,0
4	Bullet graphs	0,10	1,0
5	Speedometer dials	0,20	0,5

According to the results, obtained as a result of solving problem (10) with bounds (11), bullet graph and speedometer dial, which is reduced in size by 50%, could be used to display the $\mathrm{OSF}_{\%}$ and $\mathrm{OST}_{\%}$ indicators respectively (fig. 11).

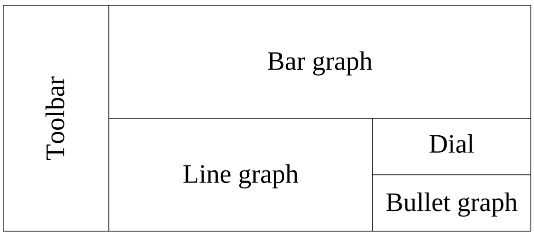

Fig. 11 – Dashboard structure according to the results in tab. 5

However according to the recommendations [6, 7], using of bullet graph instead of speedometer dial is more informative, which is confirmed by the objective function values of the problems (8) and (10):

ISSN 2079-0023 (print)
ISSN 2410-2857 (online)

$$\sum_{i=1}^{5} v_i x_i^* = 1{,}49 > \sum_{i=1}^{5} v_i y_i^* = 1{,}3, \qquad (12)$$

here x_i^* – the i th element of the problem's (8) optimal solution vector;

y_i^* – the i th element of the problem's (10) optimal solution vector.

Thus, to design the dashboard which is intended for the analysis of the products supply process state, the following visualization tools are recommended according to the obtained results (12):

- bar graph to display CtS indicator;
- line graph to display SCT indicator;
- two bullet graphs to display the $OSF_{\%}$ and $OST_{\%}$ indicators respectively.

A prototype of the designed dashboard (fig. 12) has been developed using Microsoft Power BI according to the obtained recommendations.

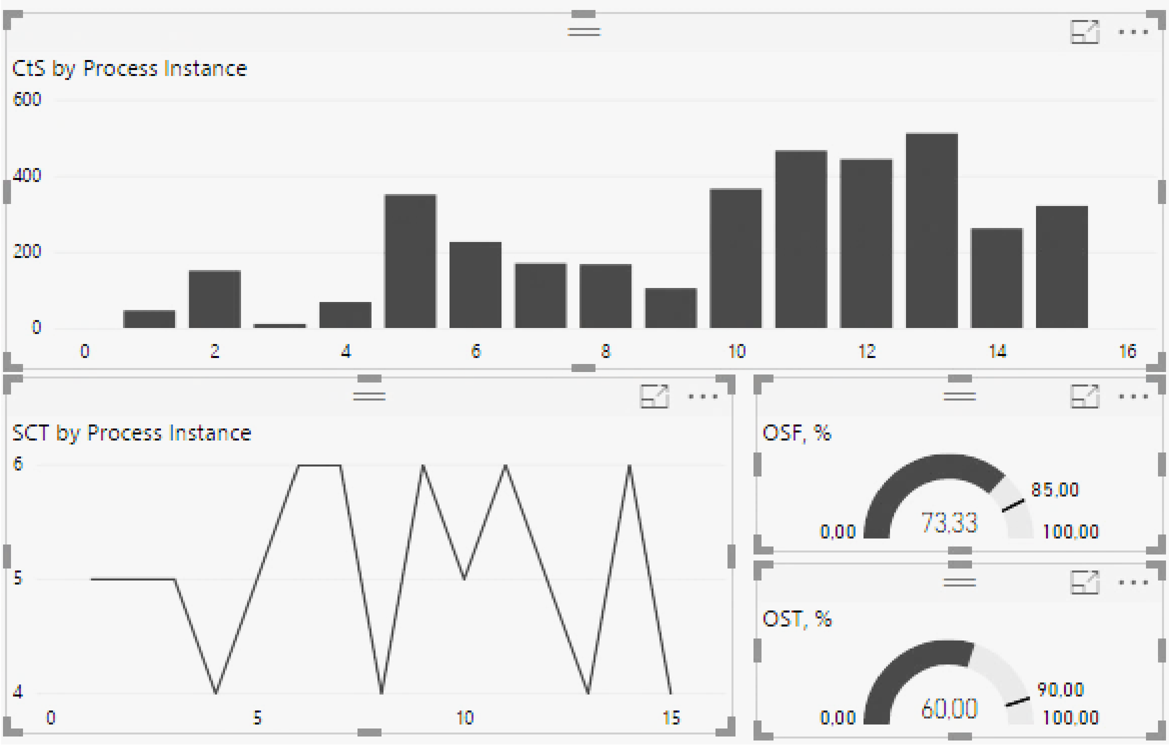

Fig. 12 – Dashboard prototype

To compare (tab. 6) the designed dashboard to the existing solutions presented on market, we have used the supply chain dashboard examples (fig. 13) provided by the online dashboard platform Klipfolio [20]:

- "Supply Chain KPI Dashboard" which contains the line graph, bar graph, and pie chart;
- "Shipping Status Dashboard" which contains the bar graph and pie chart;
- "Warehouse Order Performance Dashboard" which contains the bar graph, line graph, and speedometer dial.

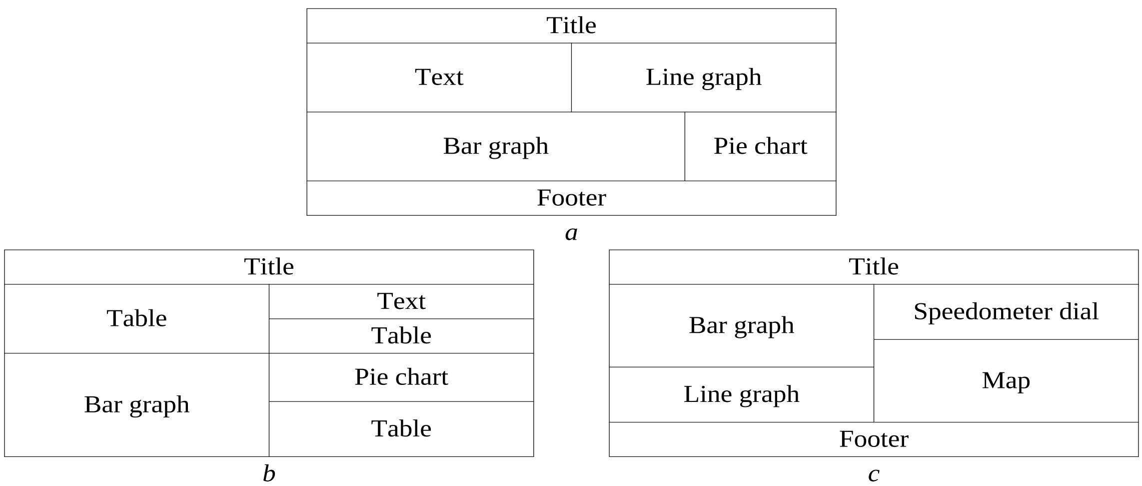

Fig. 13 – Structure of Klipfolio supply chain dashboard examples:
a – "Supply Chain KPI Dashboard"; *b* – "Shipping Status Dashboard"; *c* – "Warehouse Order Performance Dashboard"

Table 6 – Comparison of dashboard solutions

Rank	Dashboard solutions	Objective function
1	Proposed design	1,49
2	Whs. Order Performance	1,11
3	Supply Chain KPI	1,09
4	Shipping Status	0,63

According to the objective function (8) values, the proposed dashboard design (fig. 12) is more informative than supply chain dashboard examples provided by the Klipfolio.

Additional visualization tools and formal approaches used to solve the dashboard design problem will be considered in future research on this problem.

Conclusion. As the result of this study, the approach to forming dashboards which are intended to analyze business processes state, has been developed.

As a business process which state is supposed to be analyzed, we have chosen the products supply process and its second-level KPIs according to the reference SCOR model.

To measure the KPIs in order to analyze the products supply process state, we have defined the system of scales which includes the ratio scales used to measure the cost to supply and the supply cycle time as well as the absolute scales used to measure the percentage of supplies delivered in full and the percentage of supplies delivered in time.

To solve the problem of the dashboard design, we have chosen the mathematical models represented the Unbounded and Continuous Knapsack Problems, which allowed defining the number, types, and placement of the visualization tools.

As a result of the proposed approach application, the prototype of the dashboard which is intended to analyze the products supply process state has been developed.

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Received 23.10.2017

Бібліографічні описи / Библиографические описания / Bibliographic descriptions

Про один підхід до формування панелей індикаторів для аналізу стану бізнес-процесів / А. М. Копп, Д. Л. Орловський, Д. О. Кука // Вісник Національного технічного університету «ХПІ». Серія: Системний аналіз, управління та інформаційні технології. – Х. : НТУ «ХПІ», 2017. – № 51 (1272). – С. 44–52. – Бібліогр.: 20 назв. – ISSN 2079-0023.

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