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OPTIMAL MODEL FOR EVALUATING THE TOTAL DURATION OF A BUSINESS PROCESS

ОПТИМАЛЬНА МОДЕЛЬ ОЦІНКИ ЗАГАЛЬНОЇ ТРИВАЛОСТІ БІЗНЕС-ПРОЦЕСУ

When assessing the performance of business processes, it should be noted that one of the most important operational indicators and evaluation criteria of any company should be the indicator of the duration of the process completion cycle. Cycle duration is the amount of time that passes from the start of a task to the moment it is completed. Time is a critical metric for completing any task as it relates to customer satisfaction and the cost of completing that service. Based on this, the main goal of this work is to find the critical path of a business process and build a mathematical model to determine the objective function. To achieve the set goals, the problem of finding the maximum path in a directed graph constructed according to the list of works of the information system implementation project is considered. In accordance with the list of works, the relationships between them were determined, a network schedule for project planning was constructed, and the main relationships and patterns were identified. Studies of the constructed mathematical model were carried out using the MS Excel software application. The critical path of the business process of implementing an information system was found and conclusions were drawn on the total duration of the project. Thus, operations lying on the critical path require additional slack planning.

Keywords: *business process, optimality criteria, directed graph, critical path, network graph, objective function.*

Створення систем ефективного управління компаніями та організаціями різного характеру та сфери діяльності – це одне з найскладніших завдань. Універсальної методики створення таких систем управління немає, проте можлива розробка загальних принципів побудови систем управління бізнесом. До таких передових методів ефективного управління входить так званий процесний підхід до управління. Важливим фактором будь-якого бізнес-процесу буде його ефективність та завданням менеджменту є постійне покращення показників бізнес-процесу. Для того щоб пропонувати клієнтам високоякісні товари або послуги, будь-якій компанії необхідно контролювати процеси їх створення. Продумані та добре налагоджені бізнес-процеси забезпечують високий рівень якості. Основне завдання менеджменту полягає у точному визначенні найбільш суттєвих складових процесу для його подальшої оцінки, оптимізації та вироблення стандартів здійснення. Оцінюючи показники бізнес-процесів необхідно відзначити, що одним з найбільш важливих оперативних показників та критеріїв оцінки будь-якої компанії повинен бути показник тривалості циклу завершення процесу. Загальна тривалість циклу – це кількість часу, *що проходить з початку виконання завдання до моменту його завершення. Цей показник може стати конкурентною перевагою компанії. Час є критичним показником для виконання будь-якого завдання, оскільки співвідноситься із задоволеністю клієнта та вартістю виконання цієї послуги. Цей показник можна включати практично будь-якої компанії до переліку ключових показників діяльності, і він може зайняти гідне місце поряд з фінансовими показниками діяльності. Виходячи з цього, основною метою даної роботи є знаходження критичного шляху виконання бізнес-процесу, побудова математичної моделі для визначення цільової функції, при чому пропонується використання прикладного програмного забезпечення. Для здійснення поставленої мети розглянута задача знаходження максимального шляху в орієнтованому графі, що побудований за переліком робіт проєкту впровадження інформаційної системи. У відповідності до переліку робіт зроблено визначення взаємозв'язків між ними, побудовано сітьовий графік планування проєкту і виявлені основні взаємозв'язки та закономірності. Проведено дослідження побудованої математичної моделі за допомогою програмного додатку MS Excel. Знайдено критичний шлях бізнес-процесу впровадження інформаційної системи і зроблено висновки щодо загальної тривалості робіт проєкту, а саме, при збільшені тривалості робіт, які належать критичному шляху, збільшується і загальний час виконання проєкту. Таким чином операції, що лежать на критичному шляху потребують планування додаткового резерву часу.*

Ключові слова: *бізнес-процес, критерії оптимальності, орієнтований граф, критичний шлях, сітьовий графік, цільова функція.*

Formulation of the problem. The main task of management in economic systems is to identify alternative solutions, their formalized description, comparison of alternatives to actions and goals, as well as analysis of the possibilities of identifying alternatives using model experiments. These action alternatives are assessed from the point of view of the measure of achieving the set goals through optimality criteria in order to select the best, optimal one among them.

A specific feature of an economic system is that it belongs to the class of management systems, and for them the first task of implementing optimal management is the correct choice of an optimality criterion that could take into account all the most important and, perhaps, the most contradictory requirements for a given economic process.

All problems and situations that occur at different levels of the economic system must take into account the limited resources to achieve their goals. To find ways to solve them, it is necessary to conduct experimental studies and calculations. It is obvious that experimenting with economic systems is impractical, therefore the only scientifically based means of research is mathematical modeling – the most effective quantitative method for analyzing the effectiveness of management decisions.

A professional analyst in the decision-making process must identify those situations that, to one degree or another, need to be described mathematically, that is, for which it is possible to build appropriate models and, through model experiments, take the necessary information to develop a management decision [1]. A typical formulation of an optimization modeling problem is as follows: a certain process can develop according to different options, each of which has its own advantages and disadvantages, and, as a rule, there can be many such options. It is necessary to choose the best (optimal) from all possible options (applications).

To justify optimal production programs, special optimization models for solving such problems, that is, optimization modeling, are used. Finding an optimal plan is, as a rule, a complex task and refers to extremal problems, where it is necessary to determine the maximum or minimum (extremum) of a function according to certain restrictions.

The objects of optimization modeling are various areas of human activity, where in certain situations it is necessary to select the best possible course of action. The basis for this choice is finding a solution to the extremal problem using optimization modeling methods. When solving an extreme economic problem, the following points are fulfilled: an economic-mathematical model is built, an optimal plan is found, an economic analysis of the results obtained is carried out, and the possibility of their practical application is determined.

An optimization model of an economic object (system) is its simplified image, presented as a set of mathematical relationships (equations, inequalities, logical relationships, graphs, etc.) [1].

Analysis of recent research and publications. The complexity of economic systems as objects of research requires their careful study to clarify the most important functional dependencies and internal relationships between their elements. As a result, possible simplifications and assumptions are made, which obviously worsens the adequacy of the constructed mathematical models and is an excellent reason for criticism. However, only the adoption of certain assumptions allows the formalization of any economic situation.

There are no general recommendations for modeling, therefore, in each specific case, the requirements for constructing a mathematical model depend on the goals and conditions of the system under study.

In the process of applying optimization modeling in economics, a clear statement of the problem and its formalization is the most difficult stage of research, which requires thorough knowledge, first of all, of the economic essence of the processes being modeled. However, a successfully created optimization model can be subsequently used to solve other problems that are not related to the initially modeled situation. Starting with the works of L.V. Kantorovich, in optimization modeling a certain set of classical problem statements has been formed, the economic and mathematical models of which are widely used in practical studies of economic problems [1]. A. Fayol identified four basic principles of planning, calling them the general features of an optimal program of action.

Formulation of the purpose of the article. The purpose of the article is to find an optimal model for estimating the total duration of a business process, that is, the task of finding the critical path of a business process, as well as constructing a mathematical model and solving the problem using application software.

Presentation of the main material. The task of finding the maximum path is one of the main ones when modeling various business processes, as well as planning and managing projects for performing work for various purposes. The essence of the task of finding the critical path of a business process is as follows.

Many real-life projects, such as building a house and a city's transport network, manufacturing and assembling machines and mechanisms, developing technical devices and software, processing orders in trade and logistics, as well as the processes of making coffee and studying at a university, can be detailed in the form of a large-scale project number of different operations or works. Some of these operations can be performed simultaneously or in parallel, others can only be performed sequentially, when one or another operation can begin only after the completion of other operations.

For example, when building a house, you can simultaneously carry out work on interior decoration and landscaping in the area adjacent to the house. When developing software, you can simultaneously write programs for some modules and test other modules.

At the same time, the sequential execution of business process operations requires coordination of the start and end times of individual work. For example, when building a house, work on the interior decoration of the premises can begin only after the construction of the walls and roof of the house is completed. In software development, writing programs for individual modules can begin after the requirements for them are specified, for example, in the form of use cases.

In the general case, a business process model that reflects the sequence and logical relationship of the execution of individual operations or works can be represented in the form of some finite oriented graph [2]. In this case, individual operations can be represented both in the form of vertices of this graph and in the form of arcs. Since the second case of interpreting work in the form of arcs of a directed graph is more convenient for calculating the total execution time of a business process, it is traditionally used when considering the meaningful formulation of finding the critical path of a business process.

Thus, the initial information for modeling business processes is a directed graph of operations execution, each arc of which is interpreted as a separate operation or work of this business process, and a vertex as some event associated with the completion of certain operations. In this case, the time duration of individual operations is determined in the form of the weight of the corresponding arc. Based on the general logic of business process execution, the following condition is introduced: the graphical model of a separate business process must have a single initial event that initiates the start of its execution, and a single final event that records the moment of completion of its execution. In relation to a directed business process graph, this condition means that this graph must have a single vertex from which arcs emanate and a single vertex into which arcs enter.

Additionally, it is required that the considered directed graph of the business process model does not contain cycles and is connected, that is, its final vertex is reachable from the initial vertex. A directed graph that satisfies the above conditions is called a network graph or simply a network [2; 3].

One of the main tasks of business process modeling, as well as a more specific task of planning and project management, is not only the construction of a network graph of a business process that adequately reflects the general logic and technology of operations, but also an assessment of the total duration of this business process.

It should be noted that all operations of a certain business process are performed sequentially, its total duration is equal to the algebraic sum of the time intervals for performing individual operations. If the operations of a business process are performed in parallel, then the total duration of the business process is obviously equal to the maximum time interval of the operations performed in parallel. It follows: the duration of execution of a business process, represented in the general case by a network graph model, is equal to the path of maximum length connecting the initial vertex of this graph with its final vertex. This path received a special name – the critical path in the network graph.

Finding the critical path in a network graph allows you to identify business process operations that are most critical at the time of their execution. Indeed, an increase in the execution time of operations lying on the critical path leads to a clear increase in the total execution time of a business process. Thus, business process management becomes a priority and is aimed at preventing unplanned delays in the execution, first of all, of those operations that are included in the critical path of the corresponding network graph. On the other hand, reducing the time required to complete such operations due to the internal reserves of the business system can lead to a reduction in the total time to complete the entire set of operations, which is one of the goals of optimization or reengineering of business processes [4; 5].

Thus, critical path operations acquire higher priority compared to other business process operations, and the task of constructing a network graph of a business process and the critical path in this network graph becomes an important element of business process modeling. The task of finding the critical path in a network graph traditionally relates to the problems of network planning and project management, which additionally includes finding a number of special network characteristics, such as calculating early and late dates for the occurrence of events, time reserves for performing operations, and others.

Consider a directed graph: $G=(V,E,h)$ in which $V=\{v_1,v_2,\ldots,v_n\}$ – finite set of vertices, $E=\{e_1,e_2,\ldots,e_m\}$ – finite set of arcs, $h:E\to Z_+$ – weight function of arcs [6; 7]. For the mathematical formulation of the problem, it is convenient to denote individual values of the weight function of arcs through: $c_{ij}=h(e_k)$, where arc $e_k\in E$ corresponds to an ordered pair of vertices (v_i,v_j). According to the meaningful formulation of the problem of finding the maximum path in a graph, the values $c_{ij}=h((v_i,v_j))$ can be interpreted as the length of the section, costs or the cost of moving from the i -th to the j -th city. In relation to the task of finding the critical path in a network graph, each arc (v_i,v_j) is interpreted as a separate operation of the business process, and the value c_{ij} is interpreted as the time duration of the corresponding operation $\left(v_i, v_j\right)$.

Additionally, two vertices are fixed in the graph: the starting vertex v_s and the ending vertex v_t. Moreover, the length of any route in the graph is equal to the sum of the weights of the arcs included in this route [2; 3]. Assuming that the initial network graph G is connected, that is, the vertex v_t is potentially reachable from v_s and does not contain cycles, we need to determine the route of the maximum length of the initial vertex v_s to the final vertex v_t.

In the directed graph, we introduce Boolean variables x_{ij}, which are interpreted as follows. Variable $x_{ij}=1$, if arc $\left(v_i, v_j\right)$ is included in the route of maximum length and $x_{ij}=0$, otherwise, that is, if arc $\left(v_i, v_j\right)$ otherwise, that is, if arc. Then, in the general case, the mathematical formulation of the problem of the maximum route in a directed graph or the critical path in a network can be formulated as follows:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij} x_{ij} \to \max_{x \in \Delta_\beta}, \tag{1}$$

where the set of admissible alternatives Δ_β is formed by the following system of constraints such as inequalities:

$$\begin{cases} \sum_{j=1}^{n} x_{sj} - \sum_{i=1}^{n} x_{is} = 1; & (2) \\ \sum_{j=1}^{n} x_{tj} - \sum_{i=1}^{n} x_{it} = 1; & (3) \\ \sum_{j=1}^{n} x_{ij} - \sum_{i=1}^{n} x_{ji} = 0\,(\forall i \in \{1,2,\ldots,n\}, i \neq s, i \neq t; & (4) \\ x_{ij} \in \{0,1\}\,(\forall i, j \in \{1,2,\ldots,n\}. & (5) \end{cases}$$

In this case, the first constraint (2) requires the fulfillment of the following condition – the desired path must begin at the vertex v_s, constraint (3) requires the fulfillment of the following condition – the sought path must end at the vertex v_t. The third constraint (4) guarantees the connectedness of the maximum path, that is, the required path must pass through intermediate vertices of the graph. The total number of restrictions (2) – (4) is n. Finally, the last constraint (5) requires that variables only take Boolean values.

To solve the problem of finding the critical path in a network graph using MS Excel, let's consider the business process of implementing an information system. We select a list of project works, determine their duration in days and determine the relationships between the works [4]. The results are entered into the table 1.

Let's create a directed graph of a business process to complete a task that reflects the precedence relations of operations, and solve the problem of finding the maximum path in the network graph shown in Fig. 1. In this case, each arc of this network graph will mean a separate operation of some business process, and the vertex will be an event associated with the moment of the beginning or end of these operations. The dashed arrow shows fictitious work that eliminates the parallelism of operations. The duration of operations, expressed, for example, in days, is equal to the value of the weight function of each arc, indicated next to the image of this arc in the graph.

We need to find a critical path connecting the initial event 1, which corresponds to the vertex $v_1 = v_s$, with the final event 11, which corresponds to the vertex $v_{11} = v_t$ so that the total length of the path is maximum.

Table 1

List of works for the information system implementation project and identification of relationships between the works

No.	Operation	Duration, days	Previous operations
1	Announcement on the implementation of an information system (beginning of the project)	2	–
2	Selecting the system to be implemented	15	1
3	Purchasing software	7	2
4	Drawing up network design documentation	7	2
5	Purchase of technical equipment (computers, network equipment)	15	2
6	System administrator and programmer training	30	4
7	Local network installation	20	4; 5
8	Installing software on computers	5	3; 5
9	Installing network software, setting up a network	25	6; 7; 8
10	Entering initial data into the information base	40	9
11	Staff training	30	9
12	Transfer to operation (end of project)	5	10; 11

We need to find a critical path connecting the initial event 1, which corresponds to the vertex $v_1 = v_s$, with the final event 11, which corresponds to the vertex $v_{11} = v_t$ so that the total length of the path is maximum.

The variables of the mathematical model of this critical path problem in a network graph are 15 variables: $x_{12}, x_{23}, x_{34}, x_{35}, x_{36}, x_{45}, x_{46}, x_{47}, x_{57}, x_{67}, x_{78}, x_{89}, x_{8,10}, x_{9,10}, x_{10,11}$. Each of the variables x_{ij} takes the value 1 if the arc (i, j) is on the critical path, and 0 otherwise. Then the considered mathematical formulation of the problem of the critical path in a network graph can be written in the following form:

$$\begin{aligned} &2x_{12} + 15x_{23} + 15x_{34} + 7x_{35} + 7x_{36} + 0x_{45} + 0x_{46} + 20x_{47} + 5x_{57} + \\ &+30x_{67} + 25x_{78} + 30x_{89} + 40x_{8,10} + 0x_{9,10} + 5x_{10,11} \to \max_{x \in \Delta_\beta}, \end{aligned} \quad (6)$$

where the set of admissible alternatives Δ_β is formed by the following system of constraints such as equalities and inequalities:

$$\begin{cases} x_{12} = 1; \\ x_{10,11} = 1; \\ x_{12} - x_{23} = 0; \\ x_{23} - x_{34} - x_{35} - x_{36} = 0 \\ x_{34} - x_{45} - x_{46} - x_{47} = 0; \\ x_{35} + x_{45} - x_{57} = 0; \\ x_{36} + x_{46} - x_{67} = 0; \\ x_{47} + x_{57} + x_{67} - x_{78} = 0; \\ x_{78} - x_{89} - x_{8,10} = 0; \\ x_{89} - x_{9,10} = 0; \\ x_{8,10} + x_{9,10} - x_{10,11} = 0; \\ x_{12}, x_{23}, x_{34}, x_{35}, x_{36}, x_{45}, x_{46}, x_{47}, x_{57}, \\ x_{67}, x_{78}, x_{89}, x_{8,10}, x_{9,10}, x_{10,11} \in \{0,1\}. \end{cases} \quad (7)$$

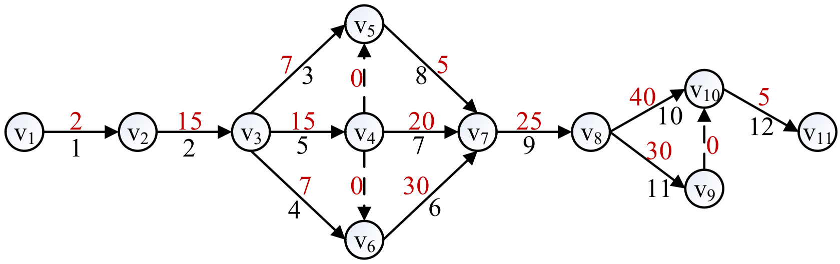

Figure 1. Network graph of the business process of implementing an information system

To solve this problem, use MS Excel to create a book and perform the following preparatory steps:

– let's enter the indices of the initial vertices and final vertices of all arcs of the corresponding graph into the MS Excel table;

– let's enter the value of the coefficients of the objective function (6);

– let us introduce the objective function (6);

– let's introduce the left side of the restrictions (7).

The appearance of the MS Excel worksheet with the initial data for solving the problem of the critical path in the network graph is identical to the image in Fig. 2.

	A	B	C	D	E	F
1	*vi*	*vj*	*cij*	**Variables:**	**Limitation:**	**Objective function value:**
2	1	2	2		=D2	=SUMPRODUCT(C2:C16;D2:D16)
3	2	3	15		=D2-D3	
4	3	4	15		=D3-D4-D5-D6	
5	3	5	7		=D4-D7-D8-D9	
6	3	6	7		=SUM(D5;D7)-D10	
7	4	5	0		=SUM(D6;D8)-D11	
8	4	6	0		=SUM(D9;D10;D11)-D12	
9	4	7	20		=D12-D13-D14	
10	5	7	5		=D13-D15	
11	6	7	30		=SUM(D14;D15)-D16	
12	7	8	25		=D16	
13	8	9	30			
14	8	10	40			
15	9	10	0			
16	10	11	5			

Figure 2. Initial data for solving the critical path problem in a network graph

To further solve the problem, you should call the solution search wizard and enter the necessary restrictions. The general view of the Solution Search Wizard parameter specification dialog box looks like this (Fig. 3).

After specifying the constraints and objective function, you can begin to search for a numerical solution. After performing the calculations using MS Excel, a quantitative solution will be obtained that looks like this (Fig. 4).

As a result of solving the problem of the critical path in the graph, the optimal values of the variables were found: $x_{12}=1$, $x_{23}=1$, $x_{34}=1$, $x_{46}=1$, $x_{67}=1$, $x_{78}=1$, $x_{8,10}=1$, $x_{10,11}=1$, others variables are 0. The found optimal solution corresponds to the value of the objective function: $f_{opt}=132$.

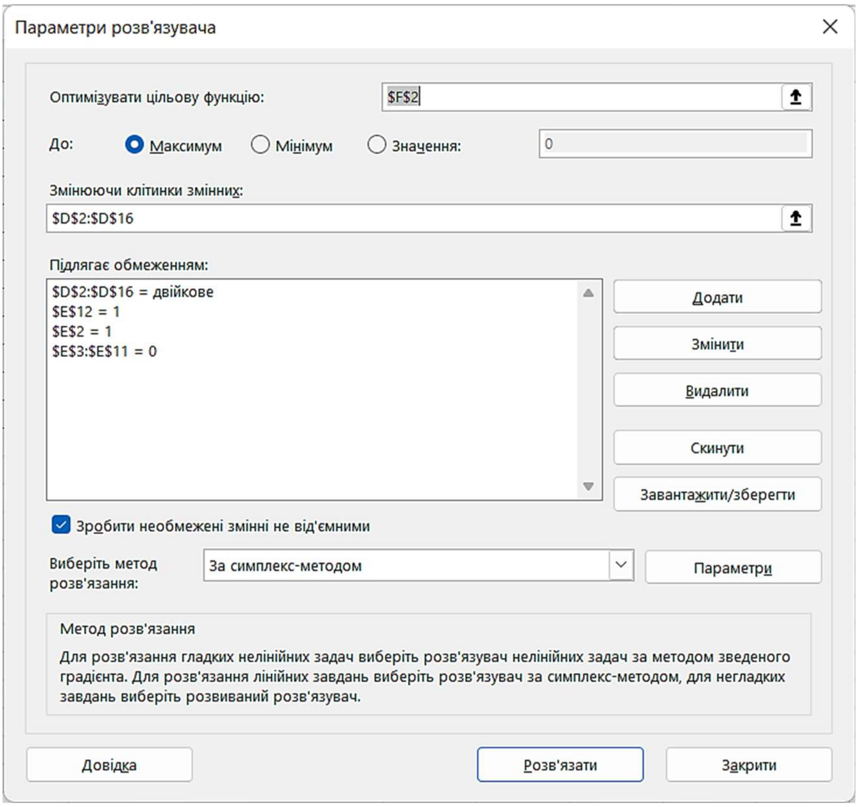

Figure 3. Restriction on the value of variables and parameters of the solution search wizard for the critical path problem in a network graph

	A	B	C	D	E	F
1	*vi*	*vj*	*cij*	**Variables:**	**Limitation:**	**Objective function value:**
2	1	2	2	1	1	132
3	2	3	15	1	0	
4	3	4	15	1	0	
5	3	5	7	0	0	
6	3	6	7	0	0	
7	4	5	0	0	0	
8	4	6	0	1	0	
9	4	7	20	0	0	
10	5	7	5	0	0	
11	6	7	30	1	0	
12	7	8	25	1	1	
13	8	9	30	0		
14	8	10	40	1		
15	9	10	0	0		
16	10	11	5	1		

Figure 4. Result of a quantitative solution to the critical path problem in a network graph

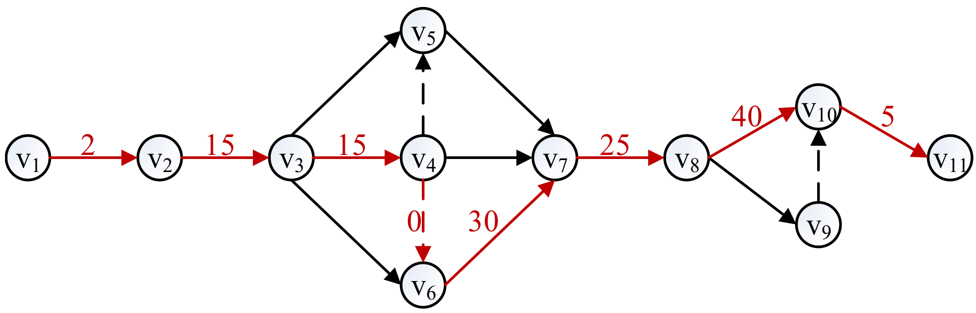

Figure 5. Critical path in the original network graph between vertices v_1 and v_{11}

Analysis of the solution found shows that the critical path in the original network graph (Fig. 1), connecting vertex 1 to vertex 8 contains the following arcs: (1, 2), (2, 3), (3, 4), (4, 6), (6, 7), (7, 8), (8, 10), (10, 11). These arcs correspond to the critical operations of the modeled business process (Fig. 5). In this case, the total duration of the critical path will be maximum and equal to 132 days, which corresponds to the total planned duration of the business process.

Conclusions. Critical nature of operations (1, 2), (2, 3), (3, 4), (4, 6), (6, 7), (7, 8), (8, 10) and (10, 11) is manifested in the fact that an increase in any of them, for example, by 1 day, will lead to an increase in the total duration of the implementation of the business process, which will be equal to 133 days. As for other operations that are not on the critical path, they have so-called time reserves, which allow for a slight increase in their duration without changing the total duration of the corresponding business process.

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