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Algorithmization of Transport Analyzes for Urban Areas – Concept and Case Studies †

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Abstract: The presentation includes the concept of algorithmization and main algorithm of the process of creating transport analyzes for urban areas. The need to develop the algorithmization proces and main algorithm results from the formation of key elements of transport analyzes as well as new possibilities of obtaining data describing both transport processes and urbanization processes. Algorithmization covers the various stages of creating a transport analysis in a systemic perspective. The presented concept uses systems engineering methods adapted to the specifics of the description of transport systems and processes in urban areas.

Keywords: algorithmization process; transport analyzes; transport modelling, urban areas

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1. Introduction

The main goal of this study is to present the key factors shaping the process of algorithmization of transport analyzes for urban areas. In the algorithmization process presented in this study, a new approach was used to represent the transport project in the mathematical modeling of transport systems and processes. The new approach is the distinction in the formal description of the transport project, the so-called *Functional-Operational Configuration of Tasks in a Transport Project (FOCT)*. This approach emphasizes the need for a holistic approach when creating transport projects, which is often forgotten in practical transport analyzes [1]. This holistic approach highlights the need to use systems engineering methods, because *Systems Engineering* is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods [2].

In transport, algorithms are a core feature for services from public transport scheduling to routing apps, bicycle sharing to self-driving technology, parcel delivery to the dispatching of ride services [3]. A review of the literature reveals that in the field of description of transport systems and processes there is a wide range of methods and algorithms for solving individual transport problems in an urban area [4], [5], [6]. In particular, it is possible to indicate methods and algorithms in the analysis of traffic conditions in transport networks, in particular, methods of estimating the capacity of intersections and sections of roads and streets in an urban area [7], methods and algorithms of searching for the shortest route in the network [8], methods and algorithms traffic assignment in transport network [4], [9], methods of estimating the demand for transport [5], [10], methods of data collection – carrying out research on transport needs and traffic measurements in transport networks [4], [5], and many other methods and algorithms for detailed analyzes of the functioning of transport systems and processes [11-14].

However, there are no methods and algorithms that holistically relate to the preparation and execution of a transport analysis for a transport project using mathematical modeling methods. In particular, there are no algorithms that could automate the performance of a transport analysis for a specific Transport Project. These are algorithms that include the analysis at the framework level, i.e. taking into account the key factors that determine the manner and detail of the analysis, and thus the type and scope of use of known domain methods and algorithms - used to solve specific problems within such an analysis. A review of the literature indicates that known systems engineering methods can be used for this purpose and that the methods and algorithms that are used in the design of intelligent transportation systems (ITS) – known as ITS architecture [15-18]. Algorithmization of transport analyzes is also expected within the program *Governing transport in the algorithmic age* [3]. However, attention is drawn to the fact that the expected benefits of algorithmic decision systems may be offset by the variety of risks for individuals (discrimination, unfair practices, loss of autonomy, etc.), the economy (unfair practices, limited access to markets, etc.) and society as a whole (manipulation, threat to democracy, etc.) [19].

Taking the above-mentioned issues into account, the concept of such an algorithm was prepared in the form of the concept of the algorithmization process. The principles of systems engineering and the extension of the approach used in the design of ITS systems based on the concept of architecture were used. This paper presents the basic assumptions of the methodology for carrying out the algorithmization process, the aim of which is to develop a framework algorithm and several detailed algorithms that will enable the automation of the process of carrying out transport analysis for urban area. The rest of the paper covers methodological assumptions (section 2), a synthetic presentation of the results (section 3), and discussion and conclusions (sections 4 and 5).

2. Materials and Methods

Algorithmization is the process of convertion an informal description of a process or a procedure into an algorithm. Informally, an *algorithm* is any well-defined computational procedure that takes some value, or set of values, as input and produces some value, or set of values, as output. An algorithm is thus a sequence of computational steps that transform the input into the output [20].

In the case of **transport analyzes** for urban areas algorithmization is the process of transforming the informal description of the transport project and the mathematical modeling of transport systems and processes, treated of course as a methodology, into an algorithm. The new approach in the presented algorithmization process is the distinction in the formal description of the Transport Project, the so-called *Functional-Operational Configuration of Tasks in a Transport Project (FOCT)*, which includes three following sets [1]:

- set of task in the field of *Mobility Management* $\boldsymbol{ToMM}$,
- set of task in the field of *Intelligent Transport Systems* $\boldsymbol{ToITS}$,
- set of task in the field of *Other Transport Services* $\boldsymbol{ToOTS}$.

The distinction of these three sets of tasks is for the purpose of preliminary domain classification for detailed interdisciplinary methods of transport project modeling in these three areas. Within the mentioned sets it is possible to select partial task configurations, which can be mapped specified subsets: $\boldsymbol{CToMM}$, $\boldsymbol{CToITS}$, $\boldsymbol{CToOTS}$. For each subset of the task configurations the characteristics of these configurations are specified, including among others characteristics of individual tasks that are part of the configuration: start date, duration, end date, priority and order of tasks, necessary resources (time, personnel, financial, etc.). The number of functions describing these characteristics for each group of tasks may be different because it depends on the complexity and type of tasks. The values of functions specified for individual sets of task configurations can be presented as:

$\boldsymbol{FCToMM}$, $\boldsymbol{FCToITS}$, $\boldsymbol{FCToOTS}$. And then the set of all functions describing all characteristics for all analyzed task configurations can be written as $\boldsymbol{FOCT} = \boldsymbol{FCToMM} \cup \boldsymbol{FCToITS} \cup \boldsymbol{FCToOTS}$. By comparing individual configurations from the presented sets of tasks, it is possible to build various variants of task configuration $\boldsymbol{VFOCT}$.

The result of transport analysis to solving transport problems using an appropriate algorithm is the selection of activities and tasks and the creation of the *Set of Variants of Task Configuration (VFOCT)*. *VFOCT* includes variants, which are then subject to multi-criteria assessment, e.g. according to known criteria: efficiency, cost, time, resources, stakeholder aspirations, etc.

The presented issues of transport analyzes with *Functional-Operational Configuration of Tasks in a Transport Project (FOCT)* are multidisciplinary, so this new approach is just in order to use *Systems Engineering* methods in the algorithmization process for transport analyzes for urban areas. This approach emphasizes the need for a holistic approach when creating transport projects, which is often forgotten in practical transport analyzes.

The holistic approach in this case concerns taking into account the multidisciplinary interdependencies between: description of transport systems, description of urban areas, description of activity of residents, description of transport needs, and the use of adequately accurate: models, methods, tools. This approach highlights the need to use systems engineering methods, because *Systems Engineering* is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods [2]. Such a system approach makes it possible to take into account interdisciplinary issues and forces the involvement of a multidisciplinary design team, which improves the quality of the transport project and its variants – *VFOCT*. Systems engineering with *FOCT* and *VFOCT* improves the algorithmization process, the result of which will be the target algorithm – more precisely, several detailed algorithms that are still in the development phase and will be partial algorithms within the main algorithm of transport analyzes for urban areas.

3. Results

The form of presentation of the content on the figures also corresponds to the process of formalization and algorithmization, because the graphic was used to present the important issues in the form of problem blocks and the links between them. It is an element of the algorithmization process, i.e. *"convertion an informal description of a process or a procedure into an algorithm"*.

Figure 1 shows the main assumptions for algorihmization with the use of systems engineering in the quasi-cycle of modification procedure that can be presented as follows:

- the following systems take part in the quasi-cycle:
  - Tests&Research Transport Project,
  - Design System (Designing Transport Project, Design process, Designed Transport Project),
  - Production System (Producing Transport Project, Production process, Produced Transport Project),
  - Operating System (Exploitation Transport Project, Exploitation process, Transport Project Handled),
  - Usage System (User Transport Project, Process of Use, Transport Project in use),
- the Usage System generates a Need formulated as the question "How to instrumentalise an action to achieve the goal?",
- the Need is transformed by the Interpreter into a design problem, which in its general form is written as the question "What and How to use to achieve the goal?",
- the Design System generates a cognitive need and a cognitive problem for the system Tests&Research Transport Project, because solving the problem requires getting to know reality and knowing the criteria for evaluating actions,

- the cognitive need concerns both substantive issues and procedural issues concerning the entire Design System, therefore an appropriate research methodology directed at this system may be necessary,
- during design, problems formulated in the form of questions "What and How to use?" "How to make it?" and "How to exploit it?",
- the result of solving the design problem is a Transport Project containing, among others the following directives concerning the subject of the project, i.e. "This is what can be created", "This is what can be exploited", "This is what can be use", and directives on the design process, i.e. "This is how to make it", "This is how to exploit it", "This is how to use it",
- on the basis of the system design, tasks and activities are performed consisting in the production of the system – static implementation of the Transport Project, i.e. a ready system, but not yet functional, e.g. a new tram line is built,
- dynamic implementation is the operation of the system in accordance with the principles of operation specified in the Transport Project – it is a system operating in a ready-for-use condition, e.g. starting tram journeys on a constructed tram line,
- the last stage of the cycle consists in the fact that the generator of the need – the Usage System – starts the use of the transport system (Transport Project), carrying out activities that achieve the goal and thus satisfies the need, e.g. transporting passengers by trams on a constructed tram line.

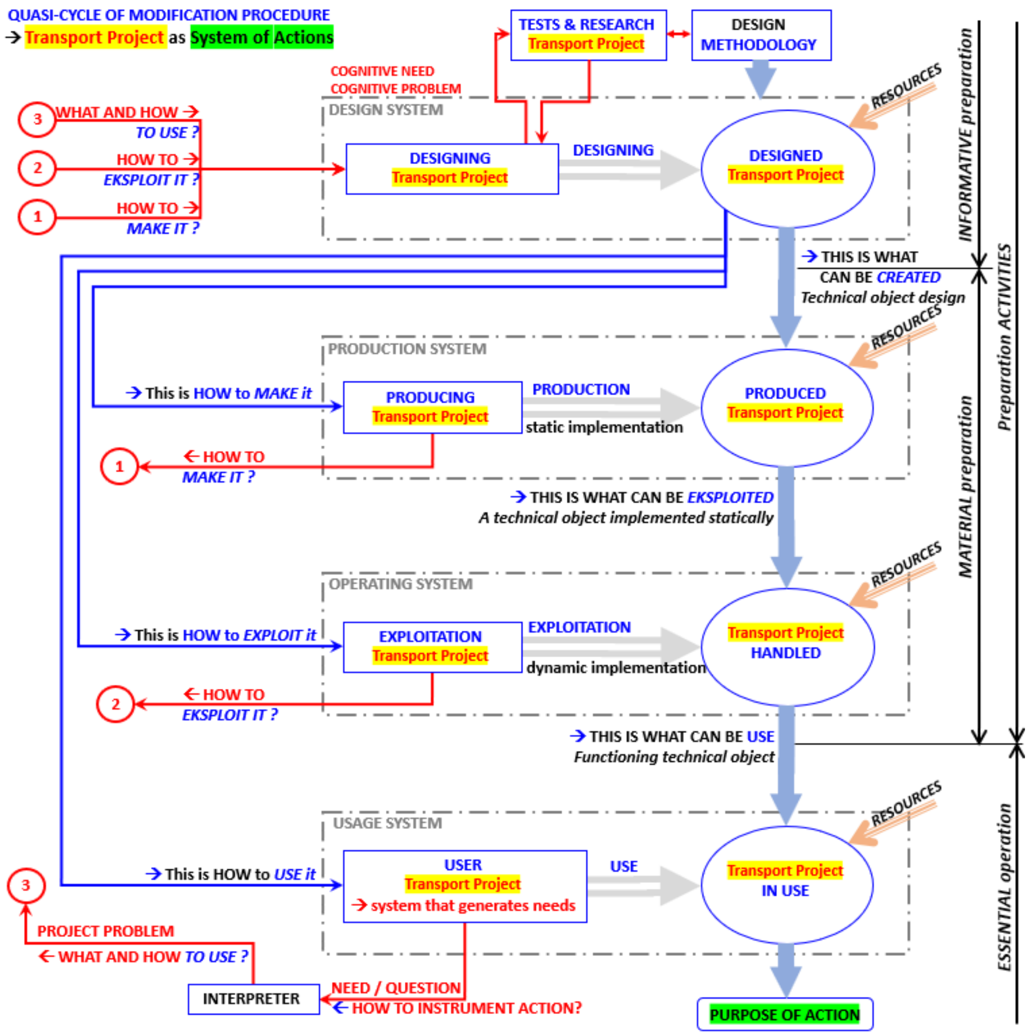

Figure 1. The main assumptions of the methodology with the use of systems engineering.

The Transport Project should take into account traffic forecasts prepared for specific forecast horizons (Fig. 2) taking into account internal changes in the existing transport systems, internal changes in urban area, changes resulting from interactions between urban area and transport systems, as well as the date of completion of construction and the beginning of the planned use transport system and subsequent horizons at appropriate intervals. The number of forecast horizons depends on the scope of the Transport Project, and it is assumed that the first forecast horizon takes into account the period, e.g. a year, in which users, under the influence of the new transport system services, change and consolidate their transport behavior and preferences. Such an assumption is related to the need to assess the effectiveness of the Transport Project in terms of its impact on the sustainable use of transport systems - evaluation in the forecasting process, i.e. ex-ante evaluation.

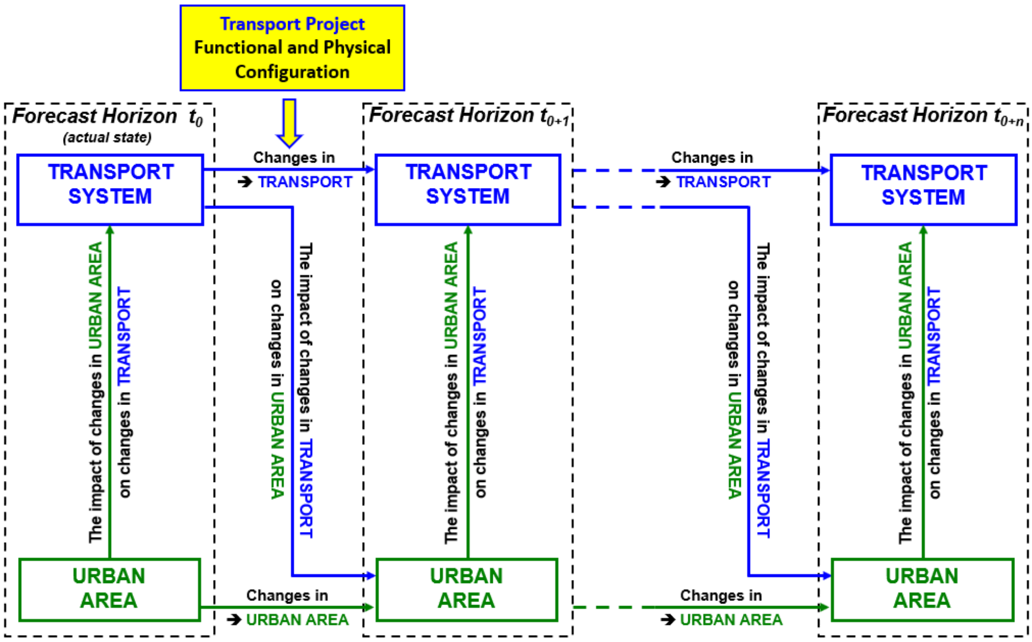

Figure 2. Dynamic relationships between the urban area and the transport system – aspects of changes and forecasts.

Figure 3 shows the main block diagram (algorithm) of transport analyzes for urban areas – in the form of a block diagram, which consists of the following blocks:

- Block 1. "Comprehensive Traffic and Transportation Studies for Transportation Modelling with Evaluation of Transport Project" – it is the basic component of the algorithm, as it is a set of methods, models and tools used for the mathematical representation of the Urban Area and Transport Systems,
- Block 2. „Proposal of Transport Project" – it is an input component of the algorithm, which includes the system description of the target Transport Project in the form of preliminary assumptions, which are the basis for the development of several variants of task configuration $\boldsymbol{VFOCT}$,
- Block 3 covers the baseline transport analyzes, i.e. „Delimitation of Study Area in TAZs – Transport Analyzes Zones", „Inventory Studies of Transportation Systems", „Transport Model Assumptions and Procesures", „Horizons of Forecasts Assumptions",
- Blocks 4a, 4b, 4c, 4d., and 5. include selected basic criteria for Urban Area delimitation, the proper application of which affects the complexity and detail of the Transport Models, which should be appropriate to the needs of the Transport Project contained in block 4d,

- Block 6. „Results of Survey and Measurement" contains all the necessary input data that enables the mathematical representation of the Transport Project in the process "Modelling of Transport Models with Transport Project and Horizons of Forecasts" – Block 7,
- Block 7. "Modelling of Transport Models with Transport Project and Horizons of Forecasts" makes it possible to calculate the necessary results (see Fig. 4) describing the effectiveness of the Urban Area transport systems in successive Forecast Horizons for the base variant (V0), in which the transport systems operate without the assessed Transport Project, and for several variants of the Transport Project (V1, V2, ... Vn) corresponding to the respective variants of task configuration $\boldsymbol{VFOCT}$,
- Block 8. „Transportation & Cost-Benefit Analysis" is a set of methods and analytical tools suitable for the evaluation of a Transport Project,
- Block 9. „Evaluations ex-ante and ex-post of Transport Project" – is a set of appropriate methods of assessing the effectiveness of a Transport Project, the results of which are measures and indicators that are decisive (the decision is made in Block 10.) about the usefulness of the Transport Project in variants of task configuration $\boldsymbol{VFOCT}$,
- Block 10. „Is the Evaluation of Transport Project acceptable?" – a positive decision ends the transport analysis of the project, and if the decision is negative, the appropriate "Indicators for Changes in Transport Project" are passed on to the corrective process "Transport Project Concept & Assumptions",
- Block 11. contains procedures for determining the appropriate "Indicators for Changes in Transport Project", which correct the "Transport Project Concept & Assumptions", and in particular the following aspects: "Structure of Transport Project", na którą to strukturę składają się m.in. „Transport Project Stakeholder Aspirations", „Transport Project Architectures Functional, Phusical & Others", "Transport Project Functional Subsystems" and "Transport Project User Services".
- Block 12. "Transport Project Accepted" completes the modeling and evaluation process of the Transport Project in several variants of task configuration $\boldsymbol{VFOCT}$.

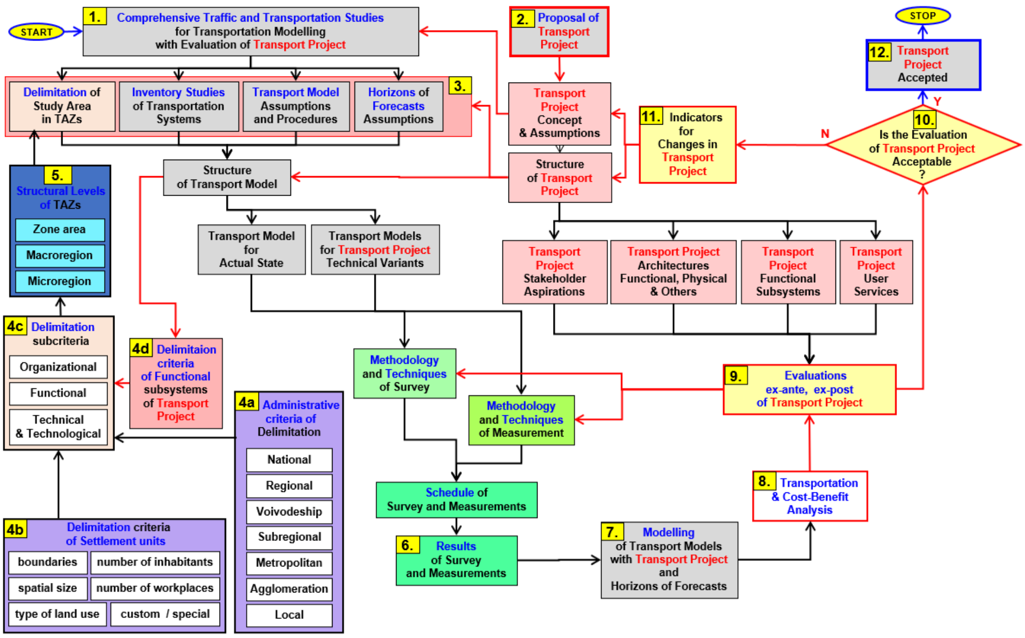

Figure 3. Main block diagram (algorithm) of transport analyzes for urban areas.

Figure 4 shows the example of results of transport modelling (traffic flows assignment in transport network) for transportation projects. This is an example of a structure for modeling the impact of a Transport Project in a metropolitan area on a macroscopic scale. The presented structure includes the following system components of data and results of transport analysis, which are the basic factors that are subject to the algorithmization process:

- Time period [AM peak hour, PM peak hour, day],
- User class [worker in industrial, worker in service, worker in private, worker in public, student of primary school, student of university, retiree, others],
- Purpose [home-work, work-home, home-school, school-home, home-other, other-home, non-home based, total],
- Flows in mode [pedestrians, bus-passengers, tram-passengers, rail-passengers, car, total],
- Mode [walk, bicycle, bus, tram, rail, car, park&ride, total],
- Source of results [survey, model],
- Technical Variants [V0, V1, V2, V3, V4, V5] – these variants are associated with variants of task configuration $\boldsymbol{VFOCT}$, these are the technical aspects of the Transport Project that shape the $\boldsymbol{VFOCT}$,
- Base Year and Forecast Horizons.

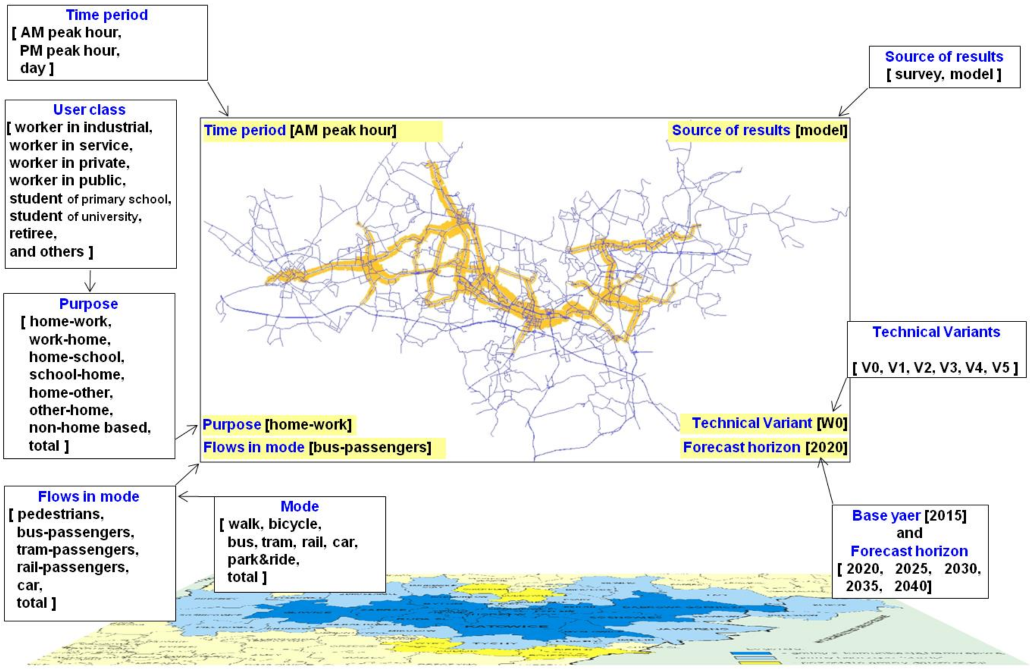

Figure 4. Example of results of transport modelling (traffic flows assignment in transport network) for transportation projects.

4. Discussion

The presented main algorithm is the concept and the basis for further work on detailed algorithms for particular key issues of transport analyzes. This algorithm was created and verified during many transport projects implemented in Poland. Detailed algorithms related to key issues are currently in the generalization phase, and because there is a large variation in the methods of solving key issues, the creation of these algorithms are iterative processes.

5. Conclusions

The development of the concept of the main algorithm required the identification of key determinants related to urban area and transportation systems, which will change as a result of changes in IT technologies, especially in connection with the Internet of Things.

The complexity of transport problems, transport services and methods of designing and optimizing these issues requires the use of systems engineering methods for a systemic and holistic approach in the algorithmization process.

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