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REPORT
on the dissertation
«Optimization models and methods for equilibrium traffic flow assignment in road networks»
presented by Alexander Yurevich Krylatov to obtain a Doctor of Science degree,
specialty 05.13.01 "System analysis, control and information processing (in applied mathematics and control processes)"

The thesis on the equilibrium traffic assignment in road networks by Alexander Yurevich Krylatov provides insightful and thoughtful optimization models and approaches based on the features of the corresponding problem. Drawing on a notably wide range of the relevant academic literature, the thesis offers original techniques for traffic assignment problem investigation.

The thesis begins by surveying the development of traffic flow theory from the early XX century. The main stages of theory development are highlighted and all necessary references are given. The relevance of the thesis becomes quite evident by virtue of the survey. Many challenges concerning equilibrium traffic assignment possesses extra significance. First, they give important algorithms which can be used in specialized software. Second, they contribute to development of nonlinear constrained optimization and operations research techniques.

Path-based traffic assignment still remains not sufficiently developed. Up to the 1990s such investigations were traditionally discarded by researchers as providing too memory-intensive and slow for large networks algorithms. Now, taking into account computer memory in new generation of computers, this approach seems to be interesting. Moreover, path-based algorithms provide not only link-flow solutions but also useful path-based solutions that are crucial in many applications. Examples of possible applications are optimal routing in route guidance system, analysis of environmental impact, fuel consumption, etc. The route-flow traffic assignment is paid by lots attention in this thesis.

The first and second chapters are devoted to principles of equilibrium traffic assignment in road networks. The first chapter deals with two principles of Wardrop, while the second one concentrates on the competitive principle which is referred to the search of Nash equilibrium. Route-flow assignment and link-flow assignment in a form of fixed-point problems are obtained; appropriate theorems are formulated and proved. Relationships between individual and group routing are established due to obtained lower and upper bounds for competitive behavioral principles. Moreover, behavioral model of traffic assignment under simultaneous selfish and group routing are formulated.

The third and fourth chapters contain investigation on methods for traffic flow assignment. First, the gradient descent method is discussed as a most popular for traffic assignment. Then, new projection algorithms for route-flow assignment and link-route assignment are suggested; the theoretical convergence of the algorithms is proved. The technique for representing linear route-flow assignment problem in a form of system of linear equations is obtained that leads to a new decomposition approach. Necessary statements are proved, the formal description of the approach is offered. Decomposition techniques for both route-flow and link-flow traffic assignment in a general topology network are presented.

The fifth and sixth chapters are devoted to network design problems. While the fifth chapter handles the capacity allocation problem, the sixth one copes with the transit network design. The capacity allocation

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control under multi-modal traffic flows is widely investigated in literature. The transit network design is considered as a problem when a special kind of transport is required to obtain the best traffic conditions in a network (the least travel time). Criteria for an optimal transit network are proposed and considered as a basis for the corresponding mathematical model. The traffic re-assignment as a reaction for optimal topology changes is investigated.

In the seventh and eight chapters, various applications are considered. The signal control problem is formulated as bi-level optimization problem. A new algorithm for OD-matrix estimation based on the dual traffic assignment problem is proposed. An approach for emission reduction based on developed traffic assignment models is suggested. A time-depended vehicle routing problem in a congested road network is stated and studied. Moreover, an investigation on a model of power smart grid with many suppliers and consumers is made. The power load flow estimation is presented in an equivalent form of link-flow assignment problem. Pricing mechanisms for transmission networks with many suppliers and consumers are discussed.

The scientific novelty and theoretical significance of this thesis are primarily due to the new models for traffic assignment and new game-theoretical class of routing games developed. Moreover, the relationship between selfish and group routing was established for the first time. The new contributions to the transit network design deal with the new methodological approaches proposed. The developed techniques allow one to consider route-flows as variables in the corresponding optimization problems. Finally, the route-flow traffic assignment consideration is one of the major points of the thesis.

The thesis contains the following key results:

1) The projection algorithms based on explicit form of projection operator for link-flow and route-flow assignment;

2) The class of network games modeling selfish and group behavior in a congested road network;

3) The decomposition technique representing a road network as a set of parallelized sub-networks;

4) The class of transit network design problems and corresponding solving approaches;

5) The new applications requiring route-flow traffic assignment instead of link-flow one;

6) The model of power smart grid based on the traffic assignment principles.

Note that these key results are originals.

The practical significance of the research is based on its initial orientation on applications. Schemes, figures and examples are paid necessary attention in the thesis. Moreover, several real-life projects relevant to this research topic were successfully completed under supervision of Alexander Yu. Krylatov.

The accuracy of obtained results is confirmed by strict proofs of all formulated mathematical statements. The most of proofs are made using approaches of nonlinear constrained optimization, algebra and mathematical analysis. The applicability of the developed methods and algorithms is confirmed by concrete examples as well as numerical experiments. The results of this research were published by author in 29 scientific papers.

Some remarks on the research study:

1. The survey on traffic assignment methods does not include bush-based and origin-based methods that are widely discussed today;
2. The network design problem was reduced to optimal capacity allocation. However, capacity allocation problem is just a part of the general network design problem.

3. The time depended vehicle routing problem is a vehicle routing problem with time depended delays on links. It is typically defined by some distribution of delays on each link during a day. Using the traffic assignment model for getting such a distribution is not an obvious improvement.
4. The traffic emission affects not only a road network itself but the corresponding urban areas at all. Thus, the Gaussian model used to estimate the emission impact seems not to be the best one. Cell-based models seem to be more appropriate for such purposes.
5. The thesis contains certain amount of misspells and mistakes.

Despite indicated remarks, that actually do not reduce the overall excellent impression on this research study, the dissertation deserves a positive assessment. Undoubtedly, the thesis is an accomplished scientific research with new fundamental results. The obtained results are of significant theoretical and applied importance, which allows us to qualify them as a scientific achievement. The topic is new and attractive and absolutely corresponds to the mentioned specialty.

The dissertation of Alexander Yurevich Krylatov titled «Optimization models and methods for equilibrium traffic flow assignment in road networks» fulfills the requirements established by Decree № 6821/1 «On the order for awarding science degrees in the Saint Petersburg State University», 01.09.2016, while Alexander Yurevich Krylatov deserves to be awarded his Doctor of science degree, specialty 05.13.01 "System analysis, control and information processing (in applied mathematics and control processes)".

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