Spatial-Temporal Modeling of Critical Infrastructure Systems

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Abstract. The application of timed Petri nets for the spatio-temporal modelling of critical infrastructure systems is essential for the effective assessment and management of the risks associated with their operation. Critical infrastructures, such as energy, transport, telecommunications and water networks, health and insurance systems, production, distribution and food security, environmental monitoring and management systems, and financial and banking services, are of strategic importance, and their disruption can have serious consequences for society and the economy. This paper proposes an approach in applied spatio-temporal modeling to understand the dynamics and interdependencies of these complex systems in space and time. The use of advanced modeling techniques and data analysis provides a detailed insight into critical infrastructure vulnerabilities, as well as the possibilities for preventing and responding to major incidents. At the same time, by applying partial differential equation models, disruption and recovery scenarios can be analyzed, in order to optimize the resilience of systems and ensure operational continuity in the face of natural and anthropogenic threats.

The model of operation and interaction of systems with critical infrastructure is defined by the system of equations, which provides for the search for the optimal solution in space and time:

$$Q(t) = opt\left[f\left(E(t), W(t), Tr(t), CI(t), H(t), F(t), B(t), G(t), En(t), P(t), X \right) \right], \quad (1)$$

where: $Q(t)$ - the quality of services offered by the system with critical infrastructure at the moment of time t; $E(t)$ - the energy system with energy and transport resources; $W(t)$ - the drinking water supply, sewerage, and wastewater treatment system; $Tr(t)$ - the road, rail, air, and public transport system; $CI(t)$ - the communication and information assurance system; $H(t)$ - the public health system and medical services; $F(t)$ - the food system and food safety; $B(t)$ - the financial and banking system; $G(t)$ - defence, public services, and emergency services; $En(t)$ - the environmental monitoring and management system; $P(t)$ - the health, life, and property insurance system; $X \in R^N$ - the work environment with N status variables; $f(\ldots)$ - space- and time-derived functions that ensure the evaluation of the relationship between the components of critical infrastructure systems.

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