A Network Motifs-Based Approach to Improving Robustness of Complex Socio-Technical Systems against Seasonal Effects

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Abstract: As a typical influential factor on the interactions between humans and technologies, the seasonal effect can significantly impact the performance of socio-technical systems (STS) and their robustness against demand fluctuation. There is an increasing need to develop new design methods that can support the capacity planning decisions for improving the robustness of STS against seasonal effects. This study develops a novel network motifs-based design approach to enhancing the robustness of STS against demand fluctuation due to seasonal changes. In this approach, as shown in Figure 1, we first use a complex network to model the STS and mine the significant motif patterns. Then, we introduce three metrics for performance evaluation and capacity planning decision-making. The first metric measures the imbalance score of a service node, e.g., the difference between the number of bikes rented and returned in a serving bike-sharing station. The second metric measures a motif's (e.g., a local system's) seasonal robustness quantified by the yearly variance of that motif's average imbalance scores. The third metric defines the capacity planning decision criterion based on system design parameters, e.g., the number of docks installed in a bike-sharing station or a supply chain warehouse's storage capacity. We argue that imbalanced capacity within an STS could make it sensitive to uncontrollable perturbations (e.g., seasonal effects). Therefore, in the final step of our approach, we formulated a design problem based on the developed metrics and criteria to optimize the capacity planning decisions to improve the robustness of STS by rebalancing the resources at critical service nodes. To demonstrate the utility of the proposed approach, a design case study on Divvy bike-sharing system in Chicago is conducted. With a focus on the three-node motifs (a subgraph consisting of three docked stations), we find a significant correlation between the difference of the number of docks among the stations in a motif and the return/rental performance of such a motif against seasonal effects. Guided by this finding, our design approach can successfully balance out the number of docks between those stations that have caused the most severe seasonal perturbations. The results also imply that the network motif can be an effective local structural representation in support of design decisions on STS' local or regional capacity planning that is impactful to system-level performance. Our approach can be generally applied in other STS where the system functionalities are significantly influenced by seasonal changes, such as transportation systems, power grid systems, and supply chain networks.

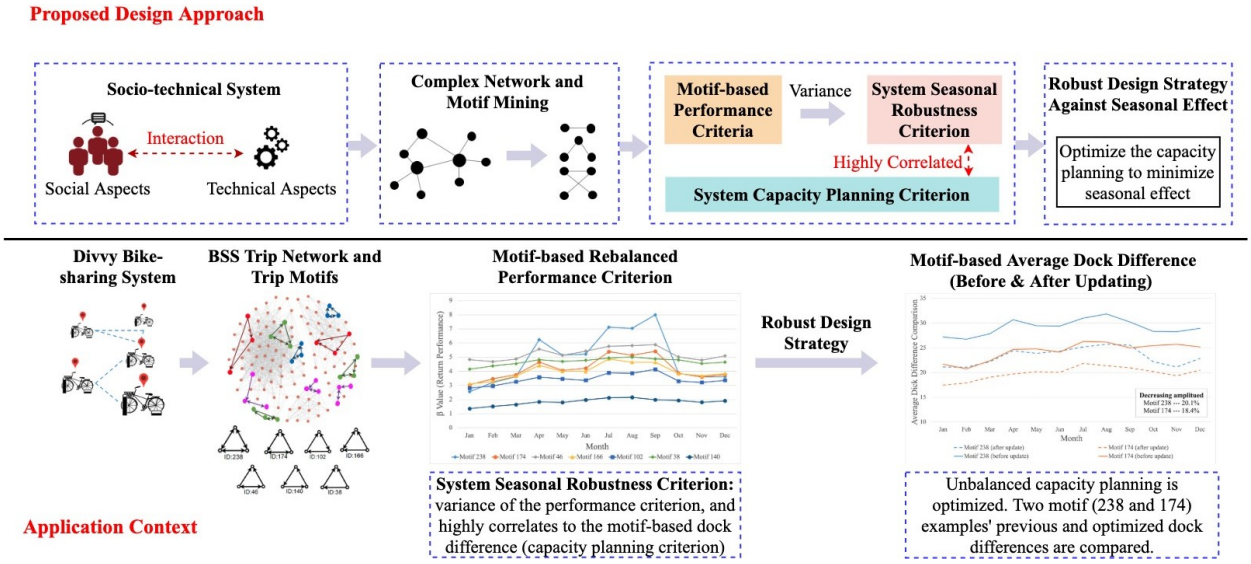

Figure 1. The proposed design approach and its application context

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