

Predicting Failures in Smart Human-Centric Ecosystems

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Abstract: In this article, we summarize our paper *Predicting Failures in Smart Human-Centric Ecosystems* [Pu26], which has been accepted at the 48th IEEE/ACM International Conference on Software Engineering (ICSE 2026).³

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1 Summary

Our paper *Predicting Failures in Smart Human-Centric Ecosystems* introduces a novel approach to predict failures in Smart Human-centric Ecosystems (*SHEs*), by combining the anomaly detection power of autoencoders with the effectiveness of transformers. To the best of our knowledge, this is the first approach specifically designed to predict failures in *SHEs*, bridging the gap between software testing and monitoring techniques, and the unique challenges posed by the intrinsic nature of *SHEs*.

SHEs, like smart cities, emerge from the composition of independently-operated and autonomous systems with smart functionalities and that evolve over time. *SHEs* lack central governance and global specifications, challenging the classic notion of correctness defined as compliance with specifications. Even if every subsystem behaves correctly, unforeseen interactions may lead to catastrophic breakdowns (as in the 2010 “Flash Crash”, a major crash of the U.S. equity market due to the unpredictable interactions of correctly behaving automatic trading systems in conditions that emerged only in production), that is, *SHE* failures. Exhaustive testing on testbeds cannot capture all conditions that emerge only in production due to the evolution of the ecosystem.

We propose *Smart human-centric Ecosystem Monitoring*, *SEM*, a novel anomaly detection approach that predicts *SHE* failures from the reconstruction error of *SHE* indicators, that is, metric values that *SEM* collects from the *SHE*. *SEM* works in three phases: (i) the

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³ <https://conf.researchr.org/track/icse-2026/icse-2026-research-track>.

preprocessor filters, synchronizes, and normalizes the input metrics time series that it receives from the *SHE*, (ii) the *denoising transformer autoencoder* identifies anomalous values of the *SHE* indicators that it receives from the *preprocessor* based on the reconstruction error, and (iii) the *predictor* raises failure alarms when the reconstruction error of the autoencoder consistently exceeds the 99th percentile of the distribution computed during training.

We evaluated *SEM* on the Digital Shadow (*DS*) of a real-world *SHE*, the ride-hailing ecosystem of San Francisco, which we built using publicly available data from multiple sources. We injected seven disruptive scenarios reported in the news and literature in the *DS*, and eleven combinations of these scenarios, for a total of eighteen critical scenarios. The results of our experiments show that (i) the *SEM* reconstruction error well reflects the *SHE* healthiness, in terms of value and stability, (ii) *SEM* correctly predicts the *SHE* failure in all the nine failing scenarios, with a time interval before the failure that allows for recovery actions, and does not raise any false alarm in the nine non-failing scenarios, (iii) *SEM* generalizes to significant variations of the *SHE*, such as the introduction of a new ride-hailing operator, with *Memory-Aware Synapses* (*MAS*) continual learning.

2 Contributions

The paper contributes to the state of the art by (i) characterizing *SHE* failures as outstanding variations of specific indexes that capture the ultimate perception of *SHE* health, (ii) providing representative examples of *SHE* failures, by referring to the case study of a ride-hailing *SHE*, (iii) defining *SEM*, *Smart human-centric Ecosystem Monitoring*, to detect *SHE* health anomalies from the reconstruction error of a suitably trained denoising transformer autoencoder, (iv) developing a prototype implementation of *SEM*, which early predicts the failing scenarios, (v) developing the Digital Shadow of a ride-hailing *SHE*, that we used for experimentally evaluating *SEM*, (vi) reporting the results of experimenting with continual learning to generalize *SEM* in the presence of significant variations of the *SHE*.

3 Data Availability

We provide *SEM* in a replication package available at github.com/NiccoloPuccinelli/SEM, to replicate the experiments presented in the paper.

References

- [Pu26] Puccinelli, N. et al.: Predicting Failures in Smart Human-Centric Ecosystems. In: Proceedings of the IEEE/ACM 48th International Conference on Software Engineering. ICSE '26, <http://star.inf.usi.ch/media/papers/2026-icse-sem-niccolo.pdf>, Rio De Janeiro, Brazil, 2026.