Application of Digital Shadows on Different Levels in the Automation Pyramid – (Extended Abstract)

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Abstract: We present the practical application of the Digital Shadow (DS) in injection molding production to manage the resulting heterogeneous volumes of data. A Digital Shadow of a system is a task- and context-dependent, purpose-oriented, aggregated data set that forms the basis for informed decision-making.

We examine two use cases located at different levels of the automation pyramid:
Geometry-dependent process configuration (Control and operational level): The DS is used at runtime to optimize the injection profile in order to achieve a more uniform melt front velocity and thus higher part quality.
Production planning and control (Planning level): The DS is used to calculate optimal machine allocation plans based on objectives such as minimum total setup time or minimum total lateness of orders.

A reference model of the Digital Shadow [Mi23] was designed and refined within the German Cluster of Excellence "Internet of Production" (IoP [Br22]) at RWTH Aachen University. For both use cases, we create a concrete data model and demonstrate how the different positioning within the automation pyramid impacts the specific data structure, the system models used, and the real-time requirements. These findings serve as a guideline for the development of future Digital Shadows in further application scenarios.

Keywords: Digital Shadow, Injection molding, Production planning and control, Method, Data, Software Engineering

1 Summary

Motivation. Activities in modern production planning and control must handle massive volumes of heterogeneous data, often generated by Internet of Things (IoT) devices. While decision-making relies on this data, usually only a task- and context-dependent subset is required for a specific purpose. The Digital Shadow (DS) concept addresses this by providing aggregated, and semantically enriched data sets. However, current research lacks

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an investigation into how the characteristics and requirements of such DSs change when applied across different levels of the automation pyramid—ranging from the shop floor to management.

Contribution. This work presents the application of a refined Digital Shadow Reference Model (DSRM) [Mi23] to two distinct use cases in injection molding through concrete realizations for each use case. The first use case, *geometry-dependent process configuration (GDPC)*, is located on the control and field levels of the automation pyramid. It utilizes a DS to optimize melt front velocity during production cycles, requiring real-time data processing to ensure part quality. The second use case, *production planning and control (PPC)*, operates at the planning level. Here, the DS facilitates the calculation of optimal production schedules based on objectives like minimal setup time or job tardiness. We demonstrate that while both cases use the same underlying reference model, their concrete realizations differ significantly in data structure, model usage, and storage requirements.

Conclusion. The investigation shows that the DS concept is flexible enough to capture relevant information across all levels of the automation hierarchy. Key differences were identified: GDPC shadows are often stored long-term for future process reuse, whereas PPC shadows are typically short-lived, representing immediate optimization results that become obsolete once the job pool changes. Furthermore, complexity in GDPC is located within individual data points, while in PPC, it resides in the relationships within the schedule. These findings provide a systematic basis for engineering future Digital Shadows as passive components within active Digital Twin systems.

References

[Br22] Brauner, P. et al.: A Computer Science Perspective on Digital Transformation in Production. ACM Trans. Internet Things 3, pp. 1–32, 2022.

[Mi23] Michael, J. et al.: A Digital Shadow Reference Model for Worldwide Production Labs. In (Brecher, C. et al., eds.): Internet of Production: Fundamentals, Applications and Proceedings. Springer, pp. 1–28, 2023.