Observability of Transportation Systems
A Methodology for Reliability Analysis in Logistics and Manufacturing

Jan Pinkowski[1] and Axel Hahn[2]
[1]*OFFIS Institute for Information Technology, Escherweg 2, Oldenburg, Germany*
[2]*Department of Computing Science, Carl von Ossietzky University,*
Ammerlaender Heerstrasse 114-118, Oldenburg, Germany

Keywords: Reliability Analysis, Material Flow, Observability, Information Flow, Logistics.

Abstract: Real world events are observed by sensors since decades, for instance in the logistics where packages are identified and tracked. This information result in an information flow. This information flow is used to control the physical material flow. Hence, the information flow is a digital representation of the physical material flow. However, to guarantee that the digital representation is in alignment to the physical world is a challenging task. Especially for scenarios with manual operations, the representation is vulnerable for errors. This paper proposes a generic approach to assure consistency between digital and physical world. The paper presents a methodology to model the monitoring of physical entities and to analyse the model to evaluate the risk of unreliable digital representation.

1 INTRODUCTION

Today, many parts of our all-day life are affected by the use of sensors, devices and machines. Especially at work, people are assisted by technique for instance in a factory to produce, transport, register, and analyse goods. Even human-free environments where those processes are automated are more and more common. However, humans as well as Computer Integrated Manufacturing (CIM) applications are working with their own representation of the physical world. The digital representation is generated by interpreting sensor data. In any cyber physical system the consistency of the digital representation and the physical world is of crucial importance. Manufacturing Execution Systems (MES) use this representation for steering and controlling of manufacturing systems. When the representation differs from the physical world, the system is not reliable.

As an example we consider cross-docking scenarios in warehouses. Each warehouse has various incoming and outgoing packages daily. Incoming trucks supply new packages to a warehouse. Within the warehouse, conveyors such as forklift trucks, belt and roll conveyors, transport the packages to defined outgoing ports of the warehouse. In order to control the transport, packages must be identified. This identification is done with sensors in the warehouse. The digital representation holds and provides this information to the conveyors. If a sensor identifies a package wrongly, the digital representation differs from the real world. Errors within the representation therefore may lead to lost packages, inefficiencies etc. In order to reduce such errors, stakeholders take individual measures to ensure the correctness of the digital representation.

However, this leads to the following questions: How good is the monitoring of the system? How can the correctness of the generation of the digital representation be assessed? In general, the digital representation abstracts from physical world systems with its processes. For complex systems the reliability of a system depends on the reliability of each of the subsystems. Our focus is to develop a generic methodology to evaluate the reliability of the digital representation of material flow by evaluating the subsystems to retrieve reliability for the overall system. The paper is organised as follows: we start with the related work in section 2, in which we reference current research and define our approach in contrast. This is followed by an overview of the methodology where all phases with the

Pinkowski J. and Hahn A..
Observability of Transportation Systems - A Methodology for Reliability Analysis in Logistics and Manufacturing.
DOI: 10.5220/0004120605480551
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 548-551
ISBN: 978-989-8565-22-8

corresponding measures will be described. Each phase of the methodology in section 3 is separated into a subsection where we present goals, measures and which techniques can be used. We conclude then with a summary and outlook for future work.

2 RELATED WORK

When planning a warehouse with forklifts, storage space and belt conveyors, simulation is most commonly used. The major goal at this stage is the efficiency and throughput of the warehouse. Those values are determined with tools like Plant Simulation (Bangsow, 2010). Our goal is to add the perspective of reliability to the planning process of transportation systems within warehouses. Therefore, we use the risk analysis method Fault-Tree-Analysis (FTA) (Lee, 1985). This method is common in safety-relevant areas such as avionic (ARP 4761) or automotive (ISO 26262). In the logistics, safety and reliability analysis is not yet prescribed. However, the application of such methods can also decrease the financial risks of errors in the transportation process. Essential for the analysis is a model of the corresponding system. Among various other model methods, there are some basic technologies such as petri nets (Petri, 1962) or Markov Chains (Spiegelhalter, 1995) that already have been applied in the logistics. Current research combines model and analysis approaches. In (Buchacker, 1999) extended fault trees are used to model the behaviour of a system and petri nets to analyse the fault tree. In contrast, (Reza, 2009) combine traditional petri nets and fault trees to derive a forward and backward reachability analysis method. Whereas our approach is a qualitative and quantitative reliability analysis, by combining risk analysis and process modelling.

3 METHODOLOGY

We introduce a generic method to detect risks of misalignment of the physical world and its digital representation for material handling operations. The sequential phases and used methods are described in the following subsections. This methodology with modelling and risk analysis functions will be implemented in a software tool. We propose the application at design and planing time of a transportation system.

3.1 Process Analysis Phase

The first phase in the methodology is the process analysis. This means that the corresponding material flow process is analysed to identify the interactions between the following components:

- Actors: active roles that interact with the environment
- Objects: passive objects that are used by an actor
- Activities: actions that relate actors with objects.

The major goal of this phase is to understand the corresponding process. This knowledge is essential for the following modelling phase and the later evaluation.

3.2 Modelling Phase

Once, the Process Analysis phase is finished, and the components are identified, we develop a model of the system.

3.2.1 Model Structure

The model structure contains modelling constructs which are the basis to build a model of the system. It also contains the relation between these constructs. An excerpt of the structure is depicted in fig. 1.

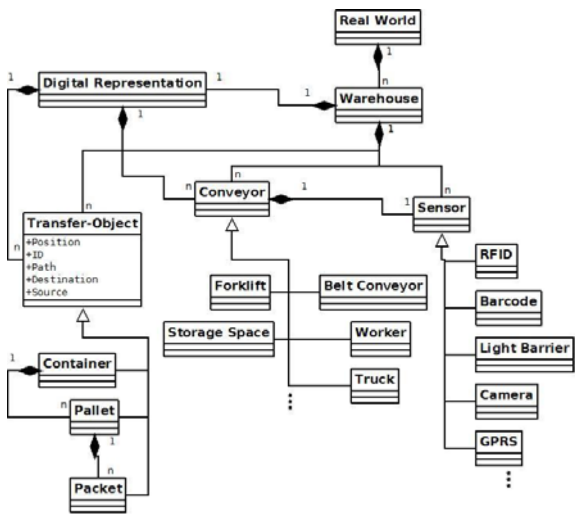

Figure 1: Excerpt of the conceptual Model.

It illustrates the three major components: conveyors, sensors and transfer-objects. These components are involved in the transfer from real world to representation. The digital representation contains transfer-objects (TO) with attributes position, id and path. The attribute id represents the unique identifier of each package. Path is an accumulation of the positions where a TO was detected. To steer the transport in the warehouse, there are also planned paths in the digital representation. For controlling purpose the planned and the actual path can be compared. The real world consists of multiple warehouses that interact with each other by conveyors that transport goods. Each warehouse has its own representation of the transportation process. A warehouse has internal and external conveyors to transport goods within, to, or from a warehouse. The conveyors and sensors within a warehouse provide information about the current status of the transportation process. This information is used to build a digital representation of the real world transportation process.

3.2.2 System Model

The system model is an instance of the model structure and contains detailed information about all identified components involved in the analysed process. An example of a system model is a special warehouse layout, with conveyors and sensors at defined positions with a defined behaviour. In general, such models are used to abstract from the complex real world using the outcome of the process analysis. In our methodology the model instance is the basis for the reliability evaluation, described in section 3.3. The content of the model depends on a specific system, as illustrated in figure 2.

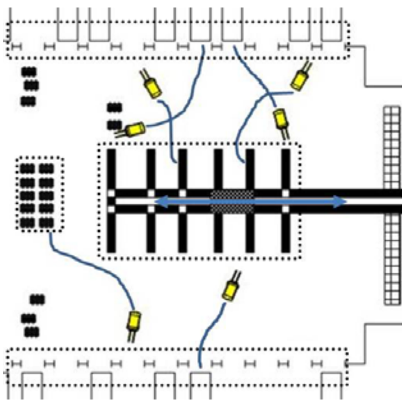

Figure 2: An Example Warehouse Layout.

The warehouse consists of forklifts, several belt conveyor modules, packages, sensors and storage space. Each conveyor has its own behaviour that must be modelled to represent the material flow. Also sensors have their own behaviour, because different sensors detect different events with different accurateness.

Sensors in the real world are not perfect. The use of sensors is always related to failures and restrictions. Typical restrictions are temperature, humidity or light restrictions where the sensor measurements contain errors. But also under ideal conditions sensors are not perfect. In order to evaluate the reliability and observability of the material flow, the sensors play a major role.

3.3 Reliability Evaluation Phase

In (Laprie, 2001) the reliability is defined as the ”continuity of correct service”. Continuity means that the reliability requirement applies to the whole runtime. Correct service in our context stands for the consistency between real world and representation. ”The validity of the reliability analysis of a system is directly related to the validity of the model used to represent the system” (Allan, 1992). In (Allan, 1992) there are two main categories of reliability evaluation techniques: analytical and simulation. A popular analytical technique in research and industrial practice is model checking (Clarke, 1999). These complementary techniques are compared in (Harris, 2006). It has been shown that simulation is not complete in terms of error detection and model-checking is vulnerable to state explosion problems in complex systems. Therefore, simulation is the common technology to analyse complex transportation processes in the logistics. These can be classified as dynamic, deterministic and discrete (Law, 2000). After a model has been analysed by simulation or model-checking, we evaluate the actual reliability in the process. In (Allan, 1992) one tool for reliability evaluation is probability theory which helps to transform knowledge of the system into a prediction of its likely future behaviour. In our case we examine the components involved in the transfer between real world and representation in order to reveal errors and to distinguish the probability for an error of a component. When all components are described with probability theory, the relation between components and the process is known, then the reliability evaluation of the components can be expanded to the whole system, for instance by quantitative fault tree analysis.

We derive reliability from observability. This means that the material flow is reliable when we observe at any time any package within the material flow. Also with a high degree of observability we cannot exclude failures during the material flow, but the system is able to recognise failures at the time they appear. This recognition is done by sensors at the spots where packages are transferred between conveyors. At these spots the system compares the digital representation with the real world. But as introduced in section 3.2.2 sensors contain errors. These errors are also part of the reliability evaluation that helps to improve the design of a planned warehouse.

3.4 Measures Phase

There are two main ways by which the reliability can be affected. The first relates to quality and the second to redundancy (Allan, 1992). Quality concerns the components used in the system, in our context the involved components on the transfer between real world and representation. This includes also personnel with their experience and training. These human factors play an important role in the reliability of systems (Allan, 1992). Redundancy helps to improve reliability of a system, in case a component fails that there is another component that can do the function and does not fail.
The reliability evaluation reveals spots with a low degree of observability. To improve observability at this spots a measure is to use redundancy and heterogeneity of sensors.

4 CONCLUSIONS

As introduced in the previous sections, we defined the methodology with its phases. Which technologies are applied exactly in the phases will be evaluated in regard to their applicability, analysed and compared in the next step. Afterwards we will define a scenario to apply this methodology to a specific transportation system. We will then analyse and model the scenario with its transportation process, and evaluate the reliability. The knowledge obtained from the first iteration of the methodology will be used to optimise the scenario system, for example with new or redundant sensors. At the end we will derive an optimised transportation system with a reliable material flow, and a refined methodology with applied specific modelling technologies.

In order to support reliability analysis as an additional aspect for planning of transportation systems, we will develop a graphical tool. This tool contains a graphical editor to create system models as described in section 3.2.2. These models consist of conveyors, sensors and packages. Defined state transitions are used to represent the material and the information flow. Based on this model we use Fault-Tree-Analysis (FTA), as an automated risk analysis method within the tool to evaluate reliability of the planned warehouse at design and planning time. The components within the model are annotated with error probabilities to enable qualitative and quantitative FTA. By combining the error probability of the components with the FTA we retrieve a calculation method with relation of the components within the transportation system. The modelling and risk analysis results are then compared to evaluate vulnerable spots in the model.

REFERENCES

Allan, R. B. (1992). *Reliability Evaluation Of Engineering Systems: Concepts And Techniques.* Springer.

Bangsow, S. (2010). *Manufacturing Simulation with Plant Simulation and Simtalk.* Berlin: Springer.

Buchacker, K. (1999). Combining Fault Trees And Petri Nets To Model Safety-Critical Systems. In *Society for Computer Simulation International* (S. 439--444)

Harris, S. V. (2006). Error Detection Using Model Checking vs. Simulation. In *High-Level Design Validation and Test Workshop.*

Clarke, E. M., Grumberg, O., Peled, D. A. (1999). *Model Checking.* The MIT Press.

Laprie, J. C. (2001). Fundamental Concepts of Dependability. In *Technical Report Seriesuniversity of Newcastle Upon Tyne Computing Science* (S. 7-12).

Law, A. M. (2000). *Simulation Modeling and Analysis.* New York: McGraw-Hill.

Lee, W. S.; Grosh, D. L.; Tillman, F. A.; Lie, C. H.; , "Fault Tree Analysis, Methods, and Applications A Review", *IEEE Transactions on Reliability*, pp.194-203

Petri, C. A. (1962). *Kommunikation mit Automaten.* Bonn.

Reza, H. A. (2009). A Safety Analysis Method Using Fault Tree Analysis and Petri Nets. In *Proceedings of the 2009 Sixth International Conference on Information Technology: New Generations* (S. 1089 - 1094). Washington DC: IEEE Computer Society.

Spiegelhalter, W. G. (1995). *Markov Chain Monte Carlo in Practice.* Chapman & Hall.