

**IMPROVING PARCEL TRANSSHIPMENT OPERATIONS –  
IMPACT OF DIFFERENT OBJECTIVE FUNCTIONS IN A COMBINED  
SIMULATION AND OPTIMIZATION APPROACH**

Uwe Clausen  
Daniel Diekmann  
Jens Baudach  
Jan Kaffka  
Moritz Pötting

TU Dortmund University  
Institute of Transport Logistics  
Leonhard-Euler-Str.2  
Dortmund, 44227, GERMANY

**ABSTRACT**

The rapid growth of the e-commerce has led to a dynamic increase of shipped parcels in recent years. Operators of transshipment terminals face the challenge to quickly sort and transfer parcels in order to successfully compete on the market and to meet their customers' expectations. A key factor to operate on high efficiency level is to provide optimal assignment decisions in the allocation of existing resources (e.g. unloading dock assignment, sorting destination assignment). We present a solution approach that closely links mathematical optimization and discrete-event simulation in an iterative way. In particular, this paper investigates the impact of different objective functions on the terminal system performance. Computational results are presented for two different transshipment terminals.

**1 INTRODUCTION**

Emerged from the traditional Less-Than-Truckload (LTL) market, the parcel delivery industry (PDI) has become an important segment of the logistics market. Parcel service providers concentrate on the transportation of small, standardized packages, that are restricted in terms of sizes and weight. Shipments are transported in comprehensive transport networks and within short delivery times. Processes within these parcel delivery networks are characterized by a high degree of cost efficiency achieved by large parcel volumes, consolidation of shipments, standardization and process automation. On international level, the market is dominated by worldwide operating integrators, such as UPS (United Parcel Service), FedEx or Deutsche Post DHL. On continental or national level several additional service providers compete on geographically restricted markets, e.g. within Europe Hermes Logistics Group, DPD (Dynamic Parcel Distribution) or GLS (General Logistics Systems).

Since the emergence of the Courier, Express and Parcel (CEP) market around forty years ago there had been a dynamic and constant market growth. Over the past decades especially the increasing demand of business customers for time-critical shipments and the trend towards smaller load units resulted in increasing parcel volumes. In recent years, however, the end customer driven demand and the rapid development of the e-commerce has become the most important growth driver. Online retailers, such as Amazon or Alibaba, gain in importance and offer a wide range of products that are shipped and delivered by parcel service providers.

In order to process the increased volumes parcel service providers have expanded their networks. A large number of depot as well as hub terminals are used and serve as the backbone of the transportation networks. The schematic material flow of these parcel transshipment terminals is illustrated in Figure 1. Incoming vehicles are assigned either to a waiting buffer area or directly to an unloading dock. In the unloading area vehicles (or swap bodies) with loosely packed parcel are unloaded with the support of telescopic conveyors. Shipments that do not meet the specification of the automatic sorting systems (e.g. very large parcels) are handled in a parallel manual sorting system. These shipments are called non-conveyable (NC) shipments.

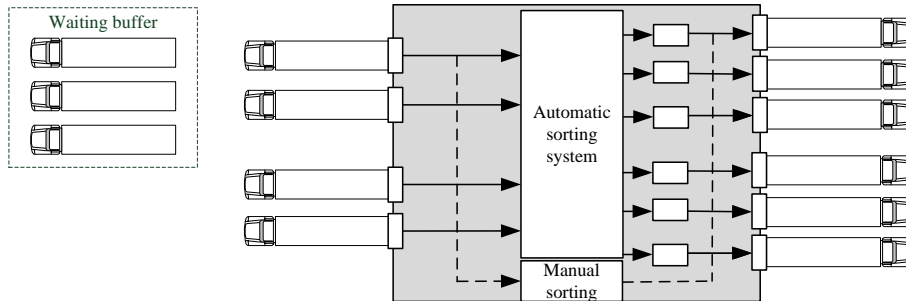


Figure 1: Material flow of a transshipment terminal.

The automatic sorting system consists of a complex conveyor network that singularizes, identifies and finally discharges the shipments at the dedicated destination points. Various conveyor layouts and also techniques to move parcels to their destination points exist. For large transshipment terminals usually slide shoe, tilt-tray or cross-belt sorters are used as these techniques meet the high performance requirements (Rushton, Croucher, and Baker 2010; Bloss 2013). In the loading area parcels are manually loaded into outgoing vehicles. Once the loading process is completed, the vehicles leave the transshipment terminal.

To efficiently operate a parcel transshipment terminal different operational decisions need to be solved. As the size and complexity of the terminals with its high speed sorting technology increases, synchronizing all different resources in a best possible way to find good operational system configuration becomes more and more important. In the unloading area the sequencing and assignment of incoming vehicles, hereafter called unloading dock assignment, influences the operational efficiency of the terminal. Typical practical restrictions of the unloading dock assignment contain maximum waiting times for incoming vehicles or technical dock restrictions (e.g. dock loading height, telescopic conveyor needed/available). In the loading area the outbound relations need to be assigned to specific sorting destination points of the main sorters (or corresponding loading docks of terminal sides). This decision, hereafter called sorting destination assignment, influences the balancing of workloads over time and should avoid flow congestion. In addition to that workloads in certain loading areas should be balanced so that the responsible workers are able to complete the loading on time in order to avoid blockings. Since the share of the destination in each vehicle is different, it is evident that the unloading dock assignment and the sorting destination assignment possesses strong interdependencies.

## 2 RELATED WORK

The modeling and optimization of freight transshipment terminals, especially of Cross Docks (CD) and LTL terminals is presented in several papers. A bilinear programming model that assigns inbound and outbound trailers to minimize forklift travel distances was developed in an early paper by Tsui and Chang (1992). Bermudez and Cole (2000) studied a similar problem with the objective to minimize total weighted distance by using genetic algorithms. Effects of trailer scheduling with look-ahead dock

assignments under various layouts are discussed by Gue (1999). Based on these papers, several authors developed more detailed and complex models using either mathematical optimization or discrete-event simulation (Yu and Egbelu 2008; Chmielewski et al. 2009; Clausen et al. 2011). Boysen and Flidner (2010) and van Belle, Valckenaers and Cattrysse (2012) presented good classifications and literature overviews of currently developed models.

A terminal in the PDI differs from the above mentioned terminals (CD, LTL) by its used handling equipment (stationary network of conveyors). Even though the amount and complexity of these terminals raised in recent years, only a few authors have focused their work on this application field. The unloading dock assignment was studied by McWilliams, Stanfield and Geiger (2005). The authors investigated the performance of different unloading schedules on small, medium and large hub terminals by using a genetic algorithm that was linked with a discrete-event simulation model (simulation-based optimization approach). Their objective was to find an unloading schedule that minimize the makespan of transfer operations. Models and algorithms were developed further in subsequent works, for example by relaxing simplifying assumptions like equal-batch-sizes of inbound trailer or using different search algorithm, such as Local Search, Simulated Annealing or Beam Search (McWilliams, Stanfield, and Geiger 2008; McWilliams 2010a; McWilliams 2010b; McWilliams and McBride 2012). Haneyah, Schutten and Fikse (2014) also focused their work on the unloading dock assignment of PDI terminals. They developed a Dynamic Load Balancing Algorithm to find the next best available trailer and to balance the workload of the sorters. Their discrete-event simulation results have shown improvements especially for heterogeneous inbound trailers sets.

In contrast to the above mentioned papers, which focus on the unloading dock assignment, other authors concentrate their work on the sorting destination assignment. Masel and Goldsmith (1997) presented a discrete-event simulation model in order to evaluate the effect of different sorting destination assignment, however no results are shown. Masel (1998) uses a Longest-Processing-Time heuristic for sorting destination assignment. By minimizing the maximum number of items assigned to one station, overall processing times are reduced. Werners, Thorn and Freiwald (2001) developed a three-dimensional assignment model in order to solve the sorting assignment of a PDI terminal. Their objective is to minimize the total distance between destination points and loading docks, since their work focuses on the manually performed internal transport with roll containers. Another contribution of the same authors also aims at minimizing the total transport distance between endpoints and loading gates (Werners and Wülfing 2010). In this paper, a mathematical model is hierarchically decomposed into two sub-problems. On top level, an even utilization of all sorting and distribution units is derived. On second level, sorting destination points are assigned to loading gates. The sorting destination assignment is also treated in the work of Jarrah, Qi and Bard (2014) and optimized by minimizing the number of trailer switches along four different sorting shifts. In a second step the authors use an additional model to optimize the internal resource scheduling of the loading workers.

In summary, it can be noted that minimizing the makespan and balancing workloads are the main objectives of current works. Good operational models for the unloading dock assignment as well as the sorting destination exist. These models, however, only focus on one decision. Our approach aims at an integrated solution that solves both, unloading dock and sorting destination assignment, in order to find a good system configuration. Our methodological approach will be described in the following section.

### **3 METHODOLOGICAL LINKING OF OPTIMIZATION AND SIMULATION**

A parcel transshipment is a complex system that consists of an automatic conveyor network and manual handling activities. Therefore using discrete-event simulation to evaluate such a terminal seems obvious and is often used in literature. However, finding the “best” system configuration can only be done in a time-consuming approach of comparing different scenarios. As the number of possible unloading dock and sorting destination assignments is very large, it becomes clear that this is a challenging task. Thus, we will make use of a mathematical optimization model here, that offers the ability to make complex

decisions and find (near) optimal solutions, admittedly on a less detailed level and without stochastic behavior.

The idea of linking the mathematical optimization model and discrete-event simulation model is shown in Figure 2. Instead of using a simulation-based optimization approach, applied for example by McWilliams for a PDI terminal, we developed a stand-alone optimization model that interacts via an interface with our detailed event-discrete simulation model (Diekmann, Clausen and Baudach 2014). In a first step the current system load (incoming vehicles), as described in Section 4, is loaded into both models. Then the mathematical model processes the optimization. As this paper focuses on the impact of different objective function of the mathematical model, our selected objective functions and the mathematical model will be explained in detail (see Section 5). After that, the gained optimal decision variables (unloading dock assignment, sorting destination assignment) are imported into the discrete-event simulation model. In a next step the detailed discrete-event simulation model performs the simulation runs and summarizes the results in the evaluation module. Here, the output of both methods are analyzed. Results of the evaluation module are shown in Section 6. The output of the detailed discrete-event simulation model is used to iteratively adapt and validate the optimization model according to the identified dynamic system behavior of the discrete-event simulation model. In this way modification and adjustments (modification module) of the optimization model can be made, which allows us to find good system configurations.

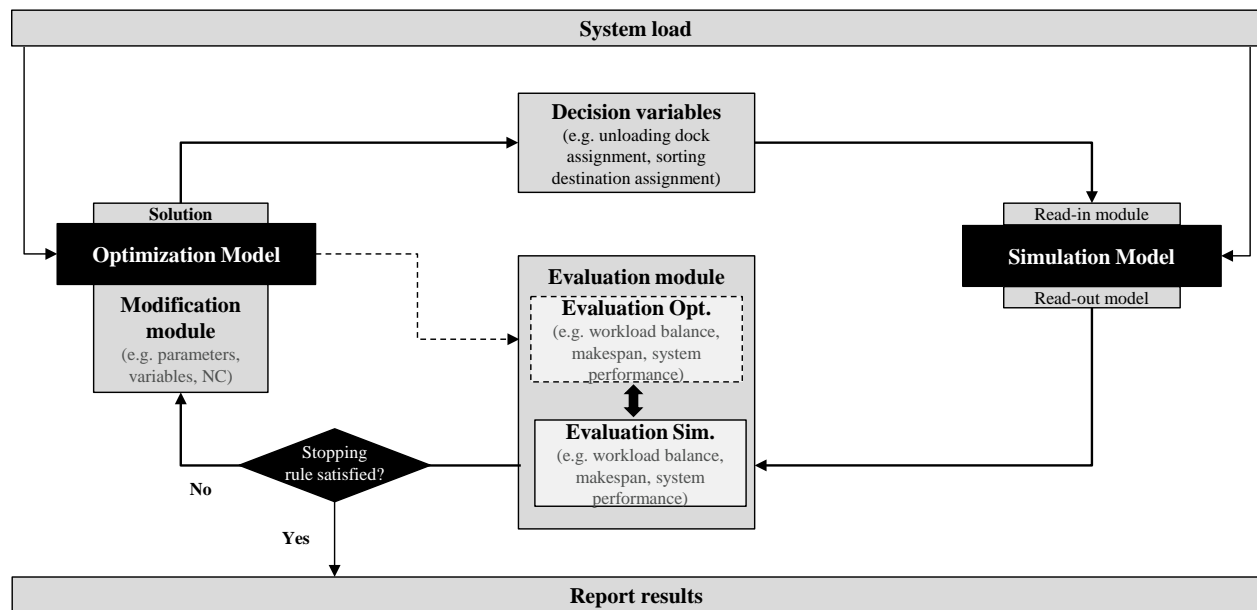


Figure 2: Methodological linking of discrete-event simulation and optimization.

#### 4 SYSTEM LOAD AND TRANSSHIPMENT TERMINALS

To study the effects of our approach, we have investigated layout designs and performance parameters of several parcel transshipment terminals. Based on this evaluation and also on real shipment data, we have created two reference terminals. We decided to choose U-shaped terminals, as this form is commonly used for large terminals and offers a good perimeter-to-area ratio. Reference system 1 (RS1) characterizes a depot terminal handling up to 4,000 parcels per hour. The second reference system (RS2) presents a modern hub reaching sorting capacities up to 35,000 parcels per hours.

#### 4.1 Reference System 1

The first depot terminal with around 6,000 m<sup>2</sup> building area is partitioned in one unloading areas at the front side of the building and two terminal sides for loading. During the investigated work shift 144 trucks are unloaded. As shown in Figure 3 quantities of truckloads vary significantly. Several local vehicles carry only a small amount of parcels (often less than 100 parcels), whereas swap bodies of long distance vehicles carry up to 1,000 parcels. On the left side a screenshot of the simulation model is displayed. Beside the automated sorting system there is a second manual sorting system for NC parcels that accounts for around 10% of total shipments.

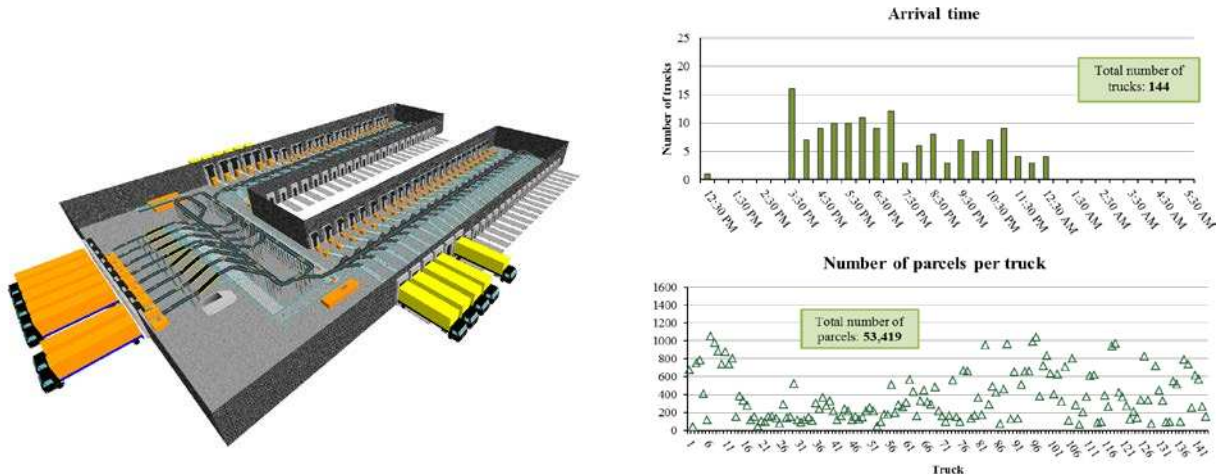


Figure 3: Reference system 1 (depot).

#### 4.2 Reference System 2

Reference system 2, as shown in Figure 4, is a large hub with 24,000 m<sup>2</sup> building area. Six unloading area are located at the front docks, feeding two main sorter that transport the parcels to two loading areas. This results into four (logical) main sorters, that have been considered in both models. The system load of the considered shift consists of 230 vehicles - all of them are swap bodies with up to 1,450 parcels.

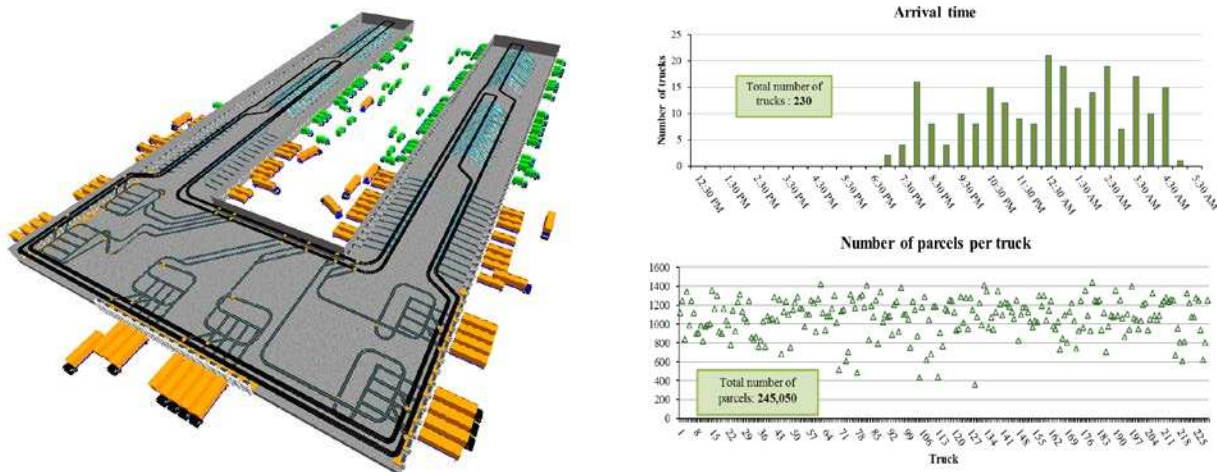


Figure 4: Reference system 2 (hub).

## 5 MODELING PROCESS AND OBJECTIVE FUNCTIONS

This section describes the modeling of our approach. First, the modeling process of the discrete-event simulation model is presented briefly. After that the mathematical model is explained. The last section discusses the evaluated objective functions.

### 5.1 Discrete-Event Simulation Model

The discrete-event simulation models have been created with ED Transport which was developed by the Institute of Transport Logistics (Neumann and Deymann 2008). It is based on the event-discrete simulation software Enterprise Dynamics (ED). In order to create parcel transshipment terminals several application specific objects have been developed (Clausen and Diekmann 2012).

In comparison to the optimization model, the discrete-event simulation model considers important aspects for the sorting operations, such as stochastic unloading operation times, sequencing orders of the parcels in the unloading process, manual handling areas for no-read-parcels as well as occupancy of the sorter-belts at the induction of parcels and recirculating parcels. As a result, detailed conclusions about the actual system behavior can be drawn by measuring the actual system performance and its impact on upstream processes. These aspects are not or only covered in less detail in the optimization model due to limitations in complexity.

### 5.2 Mathematical Model

The general modeling approach is suitable for both considered reference systems and only requires minor adjustments due to structural or technical differences. Before we discuss the selected objective functions of our models in Section 5.3 we first introduce all relevant sets, variables and restrictions. In our optimization model  $i \in I$  denotes the inbound vehicles,  $u \in U$  the unloading docks,  $s \in S$  all (logical) main sorters,  $j \in J$  the outbound relations (with subsets  $J_{long/short} \subseteq J$  for short and long distance relations),  $l \in L$  the loading docks (with subsets  $L_{long/short} \subseteq L$  for short and long distance relations docks) and  $t \in T$  all time slices. We use time slices of five minutes length as this discretization has proven to be a good compromise between model size, computing time and level of detail.

Our modeling approach combines both, assignment decisions in the unloading and loading areas of the parcel transshipment terminal. As an equal distribution of shipments among the main sorters is crucial for the performance of the sorting system within the transshipment terminal, we chose two types of binary decision variables: variables  $x_i^t$  become one if an inbound trailer  $i$  starts unloading at time slice  $t$  (at a certain unloading dock) and variables  $z_j^s$  indicate if an outbound relation  $j$  is assigned to main sorter  $s$ .

In order to avoid a quadratic model we introduce positive variables  $y_{i,t,s}^{parcel/nc}$  for the shipment flows from inbound trailer  $i$  in time slice  $t$  via main sorter  $s$ .

The linear optimization models contain different types of constraints. We will start with the commonly used unloading restrictions:

$$\sum_t x_i^t = 1 \quad \forall i \quad (1)$$

$$\sum_i \sum_{t-dur_i < \hat{t} \leq t} x_i^t \leq |U| \quad \forall t \quad (2)$$

Restrictions (1) make sure that each inbound vehicle is assigned to exactly one time slice. In addition, at each time slice the maximal number of unloading docks must not be exceeded (2). As the unloading duration of a vehicle can last several time slices (depending on its load quantity), we have to keep track of all vehicles that have started, but not finished, the unloading process in previous time slices.

The load restrictions include the unique assignment of each outbound relation to one of the main sorters (3) as well as the limited number of long and short distance docks, respectively, which are available on the terminal sides for the corresponding outbound relations (4).

$$\sum_s z_j^s = 1 \quad \forall j \tag{3}$$

$$\sum_{j \in J_{long}} z_j^s \leq |L_{long}^s| \quad \forall s, \quad \sum_{j \in J_{short}} z_j^s \leq |L_{short}^s| \quad \forall s \tag{4}$$

Correct shipment flows are guaranteed by constraints (5) and (6). First, for each inbound vehicle and each time slice of unloading the right amount of shipments has to leave the vehicle (5). Secondly, these shipments have to be correctly divided towards the main sorters and according to the assigned outbound relations (6). Note that constraints (5) and (6) are identical for NC-shipments.

$$\sum_s y_{i,t,s}^{parcel} = \sum_j \frac{ship_{i,j}^{parcel}}{dur_i} \sum_{t-dur_i < \hat{t} \leq t} x_i^{\hat{t}} \quad \forall (i, t) \tag{5}$$

$$y_{i,t,s}^{parcel} \leq \sum_j \frac{ship_{i,j}^{parcel}}{dur_i} z_j^s \quad \forall (i, t, s) \tag{6}$$

The next two constraints, summarized in (7), are required in order to obtain the makespan of all unloading, sorting and loading operations in the parcel transshipment terminal.

$$\sum_t n_t x_i^t \geq ms_{start} \quad \forall i \quad \text{and} \quad \sum_t (n_t + dur_i) x_i^t \leq ms_{end} \quad \forall i \tag{7}$$

Here,  $n_t \in \mathbb{N}$  denotes the number of time slice  $t$  and  $dur_i \in \mathbb{N}$  the duration (in time slices) of vehicle  $i$ . The two integer variables  $ms_{start}$  and  $ms_{end}$  represent the begin of unloading and the end of loading, respectively. Other practical restrictions, for example the maximum permitted waiting time of inbound vehicles after their arrival at the transshipment terminal, can be implemented by preprocessing and variable fixing.

### 5.3 Objective functions

In this paper, we focus on optimization approaches that minimize the makespan of operations or/and equally distribute/balance the shipments among the main sorters because these objectives are of main importance in order to reach a high utilization and best performance of the sorting systems. A pure makespan minimization model requires the constraints (1), (2) and (7) with the objective function:

$$\min (ms_{end} - ms_{start})$$

An optimization model that minimizes the maximum workload on one of the main sorters over all time slices consists of constraints (1) – (6) completed by the following objective function:

$$\min \max_{(s,t)} \sum_i (y_{i,t,s}^{parcel} + y_{i,t,s}^{nc})$$

The developed mathematical models were implemented via GAMS 24.3 and solved by Cplex 12.6. Table 1 shows the optimization results for RS1 and RS2.

Table 1: Optimization results RS1 and RS2.

| Reference System 1 (RS1)        |   | Time       | Unit<br>(UB, LB) | UB     | LB     | Gap    | UB     | Gap    |
|---------------------------------|---|------------|------------------|--------|--------|--------|--------|--------|
| Model / objective function (OF) |   |            |                  |        |        |        |        |        |
| OF1                             | makespan  | 54 sec     | time slices      | 126    | 126    | 0,00%  |        |        |
| OF2                             | min max workload  | 24 h       | shipments        | 154.16 | 133.41 | 13.46% |        |        |
| OF3                             | makespan + min max workload                                       | 24 h       | shipments        | 161.3  | 154.62 | 4.14%  | 206.42 | 25.09% |
| OF4                             | makespan + min max workload<br>(with fixed unloading assignments) | 108.09 sec | shipments        | 161.57 | 161,57 | 0,00%  | 206.42 | 21.73% |

| Reference System 2 (RS2)        |   | Time     | Unit<br>(UB, LB) | UB     | LB     | Gap    | UB Gap<br>(makespan solution) |        |
|---------------------------------|---|----------|------------------|--------|--------|--------|-------------------------------|--------|
| Model / objective function (OF) |   |          |                  |        |        |        | UB                            | Gap    |
| OF1                             | makespan  | 0.70 sec | time slices      | 94     | 94     | 0,00%  |                               |        |
| OF2                             | min max workload  | 20 h     | shipments        | 543.12 | 412.34 | 24.08% |                               |        |
| OF3                             | makespan + min max workload                                       | 12 h     | shipments        | 734.89 | 651.73 | 11.32% | 1563.98                       | 58.33% |
| OF4                             | makespan + min max workload<br>(with fixed unloading assignments) | 2 h      | shipments        | 735.06 | 720.37 | 2.00%  | 1563.98                       | 53.94% |

Finally, our main observations and conclusions based on extensive computational testing of real life data for each reference system are:

- As expected, just minimizing the *makespan* (OF1) is no challenge as all decision and restrictions concerning (balanced) shipment flows are neglected. This results in poor upper bound/ solutions measured by the best *min max workload* solutions (see last columns of Table 1).
- The minimization of the *maximum workload* on the main sorters (OF2) is much more challenging, especially for the big reference system RS3. But we expect the existing optimization gaps mostly to be a result of improvable lower bounds as the best upper bounds are received much earlier before the stopping time limit.
- A sequential *makespan* and *min max workload* approach (OF3 & OF4) seems to be the most promising approach as it combines a high utilization (short makespan) with a best possible performance (balanced workload) of the sorting system.

## 6 EVALUATION OF OPTIMIZATION RESULTS BY DISCRETE-EVENT SIMULATION

As described in Section 3 the optimization results were subsequently transferred into the discrete-event simulation model and evaluated. Figure 5 shows the impact of the four different objective functions for RS1. The results of the optimization model are shown on the left side, whereas the right side visualizes the results of the discrete-event simulation model. To track the workload balance (WLB) we compute the amount of handled shipments per (logical) main sorter over time. The share of workload per main sorter of each time slide is plotted on the left hand y-axis. The deviation of the output from the black dotted line (RS1 50%, RS2 25%) visualizes the imbalance. The makespan (MSP) describes the time of sorting and is shown on the horizontal x-axis. The interval between the first and the last time slice is marked with a black double arrow. Finally, the grey background shows the sorter throughput rate per time slice. The amount of sorted parcels is counted every five minutes and displayed on the right hand y-axis. Our findings and conclusions of each OF for RS1 are discussed in the following:

- OF1 minimizes the overall MSP without considering the WLB, resulting in a large gap between the two main sorters. The curve of WLB is subject to expected fluctuation due to the stochastic in the simulation model. Nonetheless the determined simulation key figures correspond with the optimization result.
- OF2 minimizes the WLB resulting in a 30% longer MSP compared to OF1. The WLB deviation is only 5% in the optimization results. The simulated WLB, however, is significantly higher (10%). The sortation of smaller amounts of parcel per time slice is superior affected by random effects in simulation.
- OF3 is a combined approach that minimizes the MSP first and optimizes the WLB afterwards. This results in a short MSP such as OF1 with an even smaller WLB than OF2. The simulation shows, that higher workloads per time slice enables a better WLB in operations. The simulated WLB (6%) is again superior than in optimization (2%) but the difference is not as large as in OF2.



- Finally, OF4 presents an alternative to OF3 as the optimization problem was simplified by fixing the truck allocation after minimizing the MSP in a first step. Anyhow, OF 4 presents a solution which is about equivalent to OF3 in terms of MSP reduction and the level of WLB.

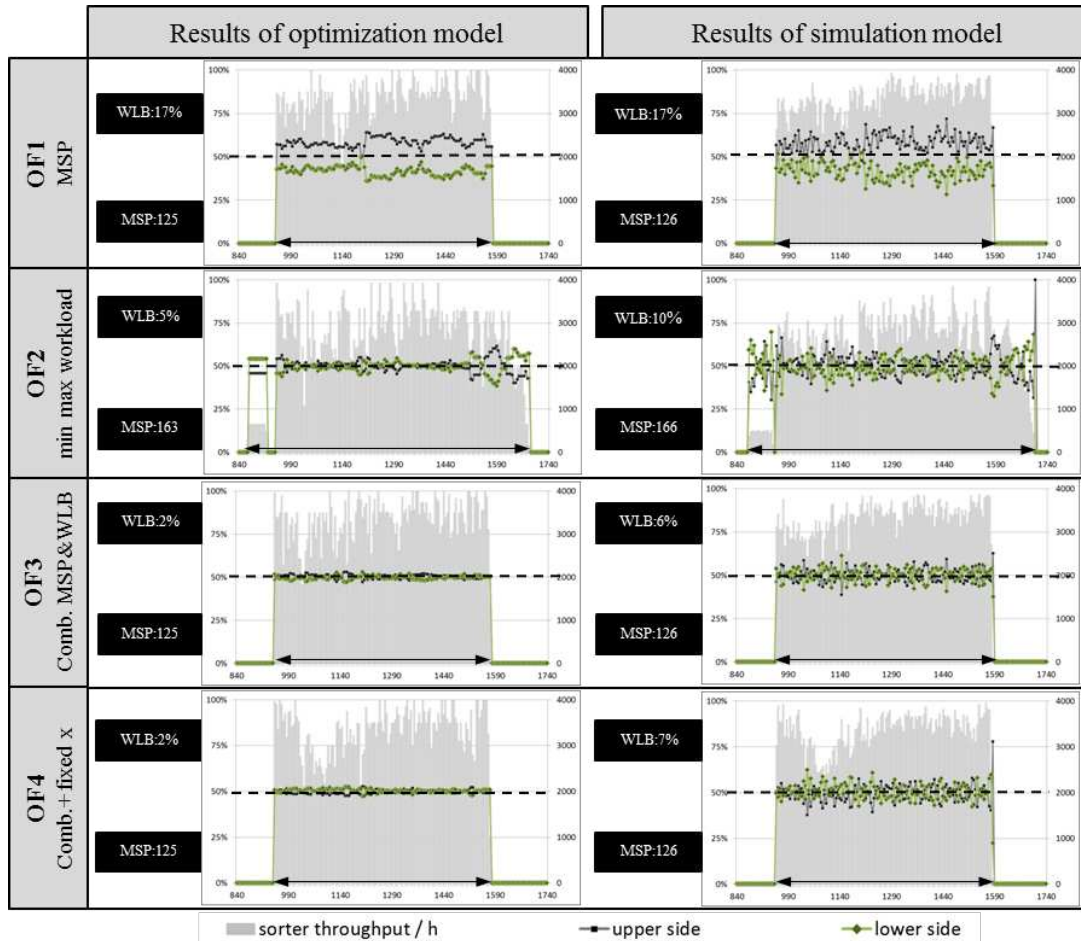


Figure 5: Results of RS1.

Computational results for RS2 are shown in Figure 6. In comparison to RS1, the WLB for RS2 shows four logical sorters. Therefore a perfectly balanced WLB is achieved at 25% workload on each sorter. Our findings and conclusions of each OF for RS2 are discussed in the following:

- As already determined in RS1, OF 1 minimizes the overall MSP accepting large fluctuation in the WLB. RS2 suffers even more from the unbalanced workload as the system does not reach the assumed maximum performance causing massive efficiency decline at the end of the shift. The resulting delay generates a gap of 38% in the overall MSP compared to the optimization model.
- Similar to RS2, OF2 tries to create a balanced workload with low system utilization. The overall MSP is 67% longer compared to the other OF which is not acceptable for practical use. Nonetheless, the achieved balance in workload creates a fluent system performance resulting in appropriately equal results in optimization and discrete-event simulation.
- OF3 again provides very good values for both WLB, MSP and sorter throughput rate. The system works stable at maximum capacity for the whole shift without disruptions or backlogs, showing approximately optimal key figures for the measured scenario.

- OF4 provides similar results as OF3. As the used computational time is lower than OF3 this objective function is highly promising for practical application.

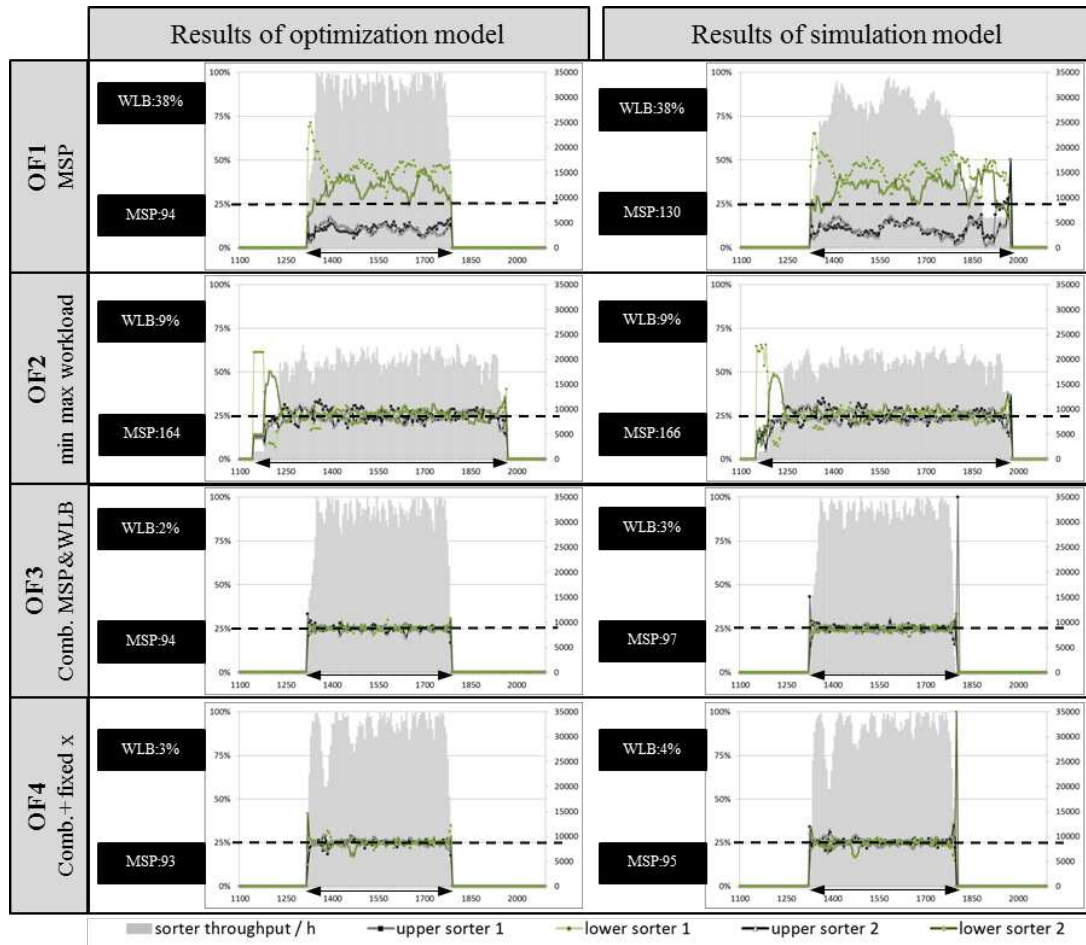


Figure 6: Results of RS2.

## 7 CONCLUSION

This paper evaluates four different objective functions to improve parcel transshipment operations in a combined optimization and discrete-event simulation approach. The results of our study show that only workload balancing (objective function 1) or makespan minimization (objective function 2) alone are not sufficient to create applicable solutions for our two tested reference terminals. Both objective functions result in poor performance or long sorting intervals. Therefore, we tested two sequential optimization approaches which combine makespan minimizing and workload balancing. The two combined approaches provided good solutions. Objective function 3 reaches the best results in terms of minimizing makespan and balancing workload. However, objective function 4 offers a worthy alternative to OF3 with significantly lower computation time. An important issue when it comes to application in practice.

The results are promising as they show that the developed objective functions lead to improvements in the operations of both depot and hub facilities. Future works within the research project will further improve and establish an iterative linking method between both optimization and discrete-event simulation model in order to find the best system configuration.

## ACKNOWLEDGMENTS

The presented results are parts of the work from the research project “Development of a combined approach that links discrete mathematical optimization and stochastic simulation for planning and operating logistics nodes (applied to transshipment terminals in the parcel delivery industry)” funded by the Deutsche Forschungsgemeinschaft (DFG – German Research Foundation).

## REFERENCES

- Bermudez, R. and M. H. Cole. 2000. “A Genetic Algorithm Approach to LTL Breakbulk Terminal Door Assignment.” In *Proceedings of the 2000 Industrial Engineering Research Conference*.
- Bloss, R. 2013. “Automation Pushes the Envelope of Postal Mail Handling Efficiency”. *Assembly Automation* 33(1): 3-7.
- Boysen, N. and M. Fliedner. 2010. “Cross Dock Scheduling: Classification, Literature Review and Research Agenda.” *Omega* 38(6): 413-422.
- Clausen, U., Kaffka, J., Diekmann, D. and L.Mest. 2011: “Impact of Different Unloading Zone Locations in Transshipment Terminals Under Various Forklift Dispatching Rules” In *Proceedings of the 2011 Winter Simulation Conference 2011*, edited by S. Jain, R.R. Creasy, J. Himmelspach, K.P. White, and M. Fu,1663-1672. Piscataway, NJ: Institute of Electrical and Electronics Engineers, Inc.
- Clausen, U. and D. Diekmann. 2012: “Simulation of Transshipment Terminals in the Parcel Delivery Industry” In *Proceedings of the European Simulation and Modelling Conference 2012*, 386-398.
- Chmielewski, A.; Naujoks, B; Janas, M. and U. Clausen. 2009. “Optimizing the Door Assignment in LTL-Terminals.” *Transportation Science* 43(2):198-210.
- Diekmann, D., Clausen, U. and Baudach, J. 2014. “A New Approach of Linking Mathematical Optimization and Discrete-Event Simulation for Operating Transshipment Terminals in the Parcel Delivery Industry.” In *European Simulation and Modelling Conference 2014*, Porto, 254-260.
- Gue, K. R. 1999. “The Effects of Trailer Scheduling on the Layout of Freight Terminals.” *Transportation Science* 33(4):419-428.
- Haneyah, S. W. A., J. M. J. Schutten and K. Fikse. 2014. “Throughput Maximization of Parcel Sorter Systems by Scheduling Inbound Containers.” In *Efficiency and Innovation in Logistics*, edited by U. Clausen, M. ten Hompel and J. F. Meier, 147-159. Springer International Publishing.
- Jarrah, A. I., X. Qi and J.F. Bard. 2014. “The Destination-Loader-Door Assignment Problem for Automated Package Sorting Centers.” *Transportation Science*
- Masel, D. and D. Goldsmith. 1997. “Using a Simulation Model to Evaluate the Configuration of a Sortation Facility.” *Proceedings of the 1997 Winter Simulation Conference*, edited by S. Andradóttir, K. Healy, D. Withers and B. Nelson, 1210-1213. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.
- Masel, D. 1998. “Adapting the Longest Processing Time Heuristic (LPT) for Output Station Assignment in a Sortation Facility.” In *Proceedings of the 7<sup>th</sup> Annual Industrial Engineering Research Conference*, Phoenix, AZ.
- McWilliams, D. L., P. M. Stanfield and C. D. Geiger. 2005. “The Parcel Hub Scheduling Problem: A Simulation-Based Solution Approach.” *Computer & Industrial Engineering* 49:393-412.
- McWilliams, D. L., P. M. Stanfield and C. D. Geiger. 2008. “Minimizing the Completion Time of the Transfer Operations in a Central Parcel Consolidation Terminal with Unequal-Batch-Size Inbound Trailers.” *Computer & Industrial Engineering* 54:709-720.
- McWilliams, D. L. 2010a. “A Genetic Based Scheduling Algorithm for the PHSP with Unequal Batch Size Inbound Trailers.” *Journal of Industrial and Systems Engineering* 4(3):167-182.
- McWilliams, D. L. 2010b. “Iterative Improvement to Solve the Parcel Hub Scheduling Problem.” *Journal of Computers & Industrial Engineering* 59(1):136–144.

- McWilliams, D. L. and M. E. McBride. 2012. "A Beam Search Heuristics to Solve the Parcel Hub Scheduling Problem." *Journal of Computers & Industrial Engineering* 62(1):1080-1092.
- Neumann, L. and S. Deymann. 2008. "Transsim-Node - a Simulation Tool for Logistics Nodes". In: *Industrial Simulation Conference*, 283-287. Lyon: The European Simulation Society.
- Rushton, A., P. Croucher, and P. Baker. 2010. "The Handbook of Logistics and Distribution Management". Kogan Page Publishers.
- Tsui, L. Y. and C.-H. Chang. 1992. "Optimal Solution to a Dock Door Assignment Problem." *Computer & Industrial Engineering* 23(1):283-286.
- Van Belle, J., P. Valckenaers and D. Cattrysse. 2012. "Cross-docking: State of the Art." *Omega – International Journal of Management Science* 40:827 – 846.
- Werners, B. and T. Wülfing. 2010. "Robust Optimization of Internal Transports at a Parcel Sorting Center Operated by Deutsche Post World Net." *European Journal of Operational Research* 201(2):419-426.
- Werners, B., J. Thorn and S. Freiwald. 2001. "Innerbetriebliche Transportoptimierung für ein Paketzentrum der Deutschen Post World Net." *OR-Spektrum* 23.4:507-523.
- Yu, W. and P.J. Egbelu. 2008. "Scheduling of Inbound and Outbound Trucks in Cross Docking Systems with Temporary Storage." *European Journal of Operational Research* 184:377–96.

## AUTHOR BIOGRAPHIES

**DANIEL DIEKMANN** attended TU Dortmund University, where he studied logistics and obtained his degree in 2010. He works at the Institute of Transport Logistics at TU Dortmund University as a scientific assistant and as a full-time PhD student, doing research in the fields of LTL and CEP terminals as well as simulation in traffic and transport logistics. His email address is [diekmann@itl.tu-dortmund.de](mailto:diekmann@itl.tu-dortmund.de).

**JENS BAUDACH** attended TU Dortmund University, where he studied business mathematics and obtained his diploma in 2006. He works at the Institute of Transport Logistics at TU Dortmund University as a scientific assistant and as a full-time PhD student. His main areas of research in transport logistics are facility location, network and transport planning, as well as scheduling of crews and resources. His email address is [baudach@itl.tu-dortmund.de](mailto:baudach@itl.tu-dortmund.de)

**UWE CLAUSEN** is the managing director of the Institute of Transport Logistics at the TU Dortmund University and director of the Fraunhofer-Institute for Material Flow and Logistics (IML). He studied computer sciences at the University of Karlsruhe (TH) and finished his doctoral thesis on transportation network optimization at TU Dortmund University in 1995. Afterwards, he worked at the "Deutsche Post AG" and joined Amazon.de in 1999. In 2001 Uwe Clausen accepted the chair "Transport Systems and Logistics" at TU Dortmund University, which became the Institute of Transport Logistics in 2011. He is amongst others chairman of EffizienzCluster LogistikRuhr and a member of the Scientific Advisory Board of German Logistics Association (BVL). His email address is [clausen@itl.tu-dortmund.de](mailto:clausen@itl.tu-dortmund.de).

**JAN KAFFKA** attended TU Dortmund University, where he studied logistics and obtained his degree in 2008. He works at the Institute of Transport Logistics at TU Dortmund University as a scientific assistant and as a full-time PhD student, doing research in the fields of intermodal freight transport and simulation in traffic and transport logistics. His email address is [kaffka@itl.tu-dortmund.de](mailto:kaffka@itl.tu-dortmund.de).

**MORITZ PÖTING** attended TU Dortmund University, where he studied Logistics. There he received his B.Sc. in 2012 and his M.Sc. 2014. He works at the Institute of Transport Logistics at TU Dortmund University as a scientific assistant and as a full-time PhD student, doing research in the fields of LTL and CEP terminals as well as simulation in transport and city logistics. His email address is [poeting@itl.tu-dortmund.de](mailto:poeting@itl.tu-dortmund.de).