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Improving the performance of elevator systems using exact reoptimization algorithms

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Improving the performance of elevator systems using exact reoptimization algorithms*

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Introduction The control of passenger elevators in a building is one of the prime examples of an online optimization problem. A suitable control should achieve small average and maximal waiting and travel times for the passengers. The waiting time and the travel time of a passenger is the time span between the release of the call and the arrival of the serving elevator at the start floor and destination floor, respectively.

In a conventional system, a passenger enters his desired travel direction using up/down buttons. In such a system, there is not only uncertainty about future passengers (the online aspect), but also uncertainty about the destination floors of the passengers waiting at a floor. This additional lack of information severely limits the optimization that can be performed. Some elevator companies therefore introduced *destination (hall) call systems*, where a passenger enters the destination floor. Such a destination call system provides more information earlier, which should allow to improve the performance of the system.

To the best of our knowledge, we propose the first exact reoptimization algorithm for scheduling a group of elevators. We use this algorithm to assess the relative performance of two kinds of destination call systems. In the *immediate assignment system*, the elevator control signals the serving elevator immediately after a call has been received. Henceforth, it has to ensure that the signalled elevator arrives at the start floor of the call and stops at the requested destination floor. All implemented systems that we know of are of this type. In a *delayed assignment system*, the elevator control can defer the decision which elevator serves a call until some time before the elevator arrives at the floor. It then signals the destination floors served by the elevator, thus selecting the corresponding passengers. Clearly, a delayed assignment system offers more potential for improving performance.

Related work Although there is much literature on elevator control algorithms, there is not much work on destination call systems yet. Gloss [3] introduced the idea of destination hall call systems, but found that computing power was insufficient to even schedule a single elevator optimally. Seckinger [4] reinvestigated the problem for a single elevator and proposed an exact algorithm for a single elevator that frequently obtained optimal solutions in less than a second. Tanaka et al. [5] propose a sophisticated Branch&Bound algorithm for controlling a single elevator, being fast enough for simulations. Both Seckinger and Tanaka et al. report that destination call systems achieve lower waiting and travel times than conventional systems.

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Reoptimization algorithm and computational results A *schedule* for an elevator is a sequence of stops, where each stop describes the corresponding floor and the destination calls picked up at that floor. To be feasible, the schedule has to contain stops at the destination floors of the destination calls picked up before. Moreover, passengers must not be transported in the wrong direction. Based on estimates for the times needed to travel between floors, the arrival times of each stop in the schedule can be computed, allowing to estimate the waiting and travel times of the destination hall calls. The *cost* of a schedule are given by the weighted sum of the *squared* waiting and travel times. We chose this objective to avoid long waiting and travel times.

A *feasible dispatch* for a group of elevators consists of a schedule for each elevator such that each destination call is picked up by exactly one elevator. We compute an optimal feasible dispatch by solving a set partitioning problem, which is a standard technique for vehicle routing problems. In order to solve the Linear Programming relaxation of the set partitioning problem, we need to solve the pricing problem. This is done using a Branch&Bound algorithm, that computes lower bounds on the waiting and travel and thus on the reduced cost of a schedule. The lower bound computation takes into account stops that may be necessary to avoid reversing the direction while passengers are loaded. Once our pricing algorithm does not find improving schedules, we solve the Integer Program consisting of the schedules found in pricing to compute a dispatch. Our reoptimization algorithm computes a new optimal dispatch each time some new information becomes known, based on the available information.

We evaluated our algorithm using simulation. In the simulation we assumed that passengers enter the cabin in first-come-first-served manner. We consider a building with an elevator group of four elevators serving 16 floors. The passenger data used in our experiments came from the software tool *Elevate* [2]. We look at four templates defined by Elevate that represent different traffic patterns. These mimic the typical traffic situations in an office building. In the morning, passengers enter the building from the ground floor, causing up-peak traffic (U). Then there is some interfloor traffic (I) between the floors. During lunch traffic (L), people leave and reenter the building via the ground floor. Finally, there is down-peak traffic (D) when people leave the building in the afternoon. The simulation ran on ten realizations of each of the traffic patterns.

First we have a look at the computation times needed to solve the reoptimization problems and the quality of the solution obtained (see Table 1). Note that since we only use the schedules from solving the LP relaxation we do not necessarily find an optimal dispatch. This approach seems justified since the average integrality gap between the cost of the resulting dispatch and

	immediate assignment				delayed assignment			
	avg gap	max gap	avg time	max time	avg gap	max gap	avg time	max time
U	2.9%	59.6%	0.17 s	1.76 s	0.0%	1.0%	0.61 s	139.44 s
I	1.0%	33.7%	0.12 s	0.17 s	0.0%	3.0%	0.11 s	0.17 s
L	1.0%	40.7%	0.17 s	0.30 s	0.0%	6.1%	0.15 s	4.49 s
D	1.0%	37.5%	0.16 s	0.35 s	0.0%	4.2%	0.16 s	1.55 s

Table 1: Evaluation of the performance of our exact reoptimization algorithm, both for immediate and delayed assignment systems. Shown are the average and maximum integrality gap and the average and maximum computation times for each reoptimization problem.

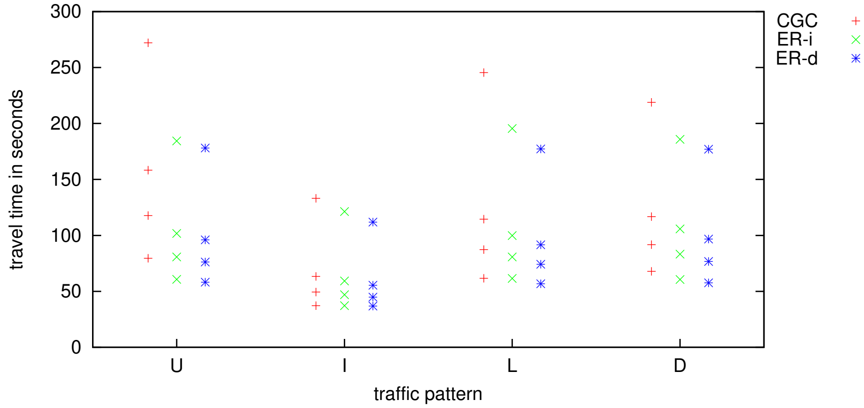

Figure 1: Simulation results for a group of four elevators in a 16-floor building.

the optimal cost of the LP is small. Moreover, most of the snapshot problems are solved well within one second.

To measure the quality of service achieved by our control algorithm we look at the 50%, 75%, 90%, and 100% quantiles of the travel times. We compare three kinds of systems: The conventional system with up/down buttons is represented by the algorithm CGC [1] that is designed to perform well in most traffic situations. The immediate assignment system and the delayed assignment systems are represented by algorithm ER-i and ER-d, respectively, which is our exact reoptimization algorithm applied to the corresponding system. From the quantiles plotted in Figure 1 it is evident that ER-i outperforms CGC, with the exception of the 50%-quantiles for interfloor and lunch traffic. ER-d outperforms both CGC and ER-i on all quantiles.

Conclusion Our simulation results indicate that destination call systems are superior to conventional ones and that rigorous optimization algorithms can exploit their potential. Delayed assignment systems offer more potential than immediate assignment systems and it will be interesting to see whether such systems can be realized.

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