**Real-time vehicle reassignment to balance demand in a multi-zonal transit network**

(Alternative title :multi-line short-turning procedure to balance vehicle loads)

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*Topic for form: topic: routing and scheduling in transport systems*

Traditionally, the transit vehicle run-cutting happens as the last step in a sequential planning process. Routes are designed to serve OD points, frequencies are set to serve expected/historical/average demand, and vehicles are assigned to these routes subject to run-time and driver constraints. Vehicle blocks are optimized to minimize dead-heading and non-revenue hours of a vehicle, and blocks are assigned to drivers subject to labor constraints (Weider et al., 2015; Haase et al., 2001). With the advent of computer-aided dispatching and automatic vehicle location (CAD AVL) technologies, this planning and assignment process has not changed a great deal. However, with the introduction and eventual propagation of autonomous vehicles, and the potential for partially- or fully-autonomous vehicles to serve fixed bus routes, it stands to reason that the labor laws could be relaxed due to the reduced strain on drivers' or conductors’ cognitive load.

Beyond the initial vehicle and crew scheduling problems, incident management calls for more dynamic vehicle management. When bus break-downs create unexpected vehicle and customer delays, agencies have standard procedures to place floating vehicles in service or convert buses from other routes to manage the disruption. These procedures require information about the location and capacity of nearby buses and communication between bus drivers and a control center.

Recent approaches in emergency evacuation and incident management have sought to dynamically adjust rail and bus transit schedules to minimize passenger discomfort (Barrena et al., 2014; Canca et al., 2015; Walker et al., 2005). These approaches are limited in considering only a single depot, single line or service or single vehicle type. Existing research has used short-turning, risk-based approaches, and demand analysis to insert vehicles where needed on bus and rail networks (Talarico et al., 2015). In this paper, we outline and simulate a methodology for "dynamic run-cutting", whereby as demand fluctuates on a network throughout the day, vehicles can reposition themselves in response to variations in demand loads across the network. Building on the recent work in emergency management and cash-in-transit vehicle routing problem, this paper applies similar logic to dynamic operations for more frequently occurring disruptions and inefficiencies. Historic demand data is analyzed to understand (1) where demand is changing throughout the day and (2) where vehicles are running unproductively. This historical data provides key information that informs the search procedure of a hard optimization problem that needs to be solved in real-time. Once a bus is empty and there are other buses serving the same route nearby (e.g. within a 1-5 minute headway), the driver can confirm prompts from the CAD AVL system that no passengers remain on-board. We describe the series of decisions and conditions under which a bus would be re-routed given location, onboard passengers, and demand elsewhere on the network and simulate the operations. We then formulate an optimization problem to minimize passenger wait time and crowding subject to available fleet and crew. Test cases are used to examine the potential improvements in service as well as the associated costs of the proposed dynamic assignment procedure. The primary contributions of this work are the multi-zone analysis and non-homogenous fleet.

A dynamic vehicle reassignment method would be appropriate as transit agencies introduce autonomous vehicles into their fleets, as such a transition is expected to take many years. Given capital and maintenance budgets, batches of vehicles are purchased as older ones are phased out. Thus, the simulation accounts for the fact that only a portion of routes and/or vehicles may be eligible for dynamic run-cutting opportunities, and the methodology identifies the conditions which would make a route or zone a good candidate for dynamic operations.

Current applications and future research directions will also be discussed. With the recent influx of demand-adaptive techniques and services (e.g. Uber, Lyft, Bridj, Kutsuplus) to serve varying loads across a network, researchers have asked what traditional transit agencies can learn from their approaches. Given the large fleets and institutional barriers that legacy agencies face, responding to customer demands in real-time represents a formidable obstacle. A real-time vehicle reassignment procedure would be a near practice-ready tool to assist transit agencies and urban DOTs in balancing network loads during peak times. The integration of (and sensitivity of the solution to) a shared autonomous fleet of smaller cars (4-7 passengers) and minibuses (10-20 passengers) are also discussed.

References:

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[[Gabriel E. Sánchez-Martínez](http://trrjournalonline.trb.org/author/S%C3%A1nchez-Mart%C3%ADnez%2C+Gabriel+E), [Haris N. Koutsopoulos](http://trrjournalonline.trb.org/author/Koutsopoulos%2C+Haris+N), [Nigel H. M. Wilson](http://trrjournalonline.trb.org/author/Wilson%2C+Nigel+H+M). Event-Driven Holding Control for High-Frequency Transit](http://trrjournalonline.trb.org/doi/abs/10.3141/2535-07) Transportation Research Record No.2535, pp. 65–72

**2/16 Meeting Notes**

There are two extreme cases where a bus should be dynamically routed:

1. A bus is empty and there is likely higher demand on other routes than on the remainder of the bus’s current route (e.g. a 156 becoming a Diversey bus when it reaches Stockton & Cannon Drive)
2. For buses that will run express at some point along their route, as soon as the bus is full and additional boardings would result in disproportionate dwell times, the bus should begin its express run early (e.g. a 136, if full by Montrose, Wilson, or Lawrence, would get on LSD at that point instead of proceeding to Irving Park).

For these extremes and all intermediate cases, a series of rules is proposed to dictate when to cut, where to cut, and which buses will cut:

1. If Bus 1 is changing route, the Bus 2 (remaining on its route) must be within X minutes behind Bus 1.
   1. If Bus 1 is changing route, there may be cases where Bus 0 could be informed Y minutes prior to the switch.
   2. If buses 0-2 are within X minutes of one another, Bus 1 would have additional rules for skipping stops.
2. Is buses are bunched distance X from route terminus, reroute 1 or more buses
3. When bus is empty, it is eligible for changing routes immediately and should not pick up additional passengers
   1. Driver would confirm emptiness of bus
   2. Autonomous vehicle would have sensors to confirm emptiness of bus
4. When bus is at X% [crush] capacity, it should be permitted to begin its express run from that point forward.
   1. Must inform passengers the bus will run express and there is a follower.
5. When a bus enters a pre-defined dynamic zone, the corridor may be re-optimized. For example, east of Clark, west of LSD, north of Division, South of Diversey could be a dynamic zone for reassignment.
6. Where there is a high marginal cost on alternate routes, defined as wait time and comfort of individuals who would benefit from a bus route reassignment, express or reassignment should be considered.
7. After changing routes, a bus must eventually return to the **appropriate** garage and must satisfy driver labor/schedule rules (breaks, shift end)
   1. Bus may need to recover initial route
   2. If driver within X minutes of end of shift or break, do not reroute.
8. Buses may deadhead on the way to layover/staging so long as the destination board reflects the pattern end point
9. OPTIONAL service planning potential
   1. If X% of customers are expected to transfer, run a special pattern (but this could be regularly scheduled pattern)
   2. If buses are Y% full between time 1 and time 2, assign level of priority for available buses to be rerouted. Evaluate feeder routes for dynamic potential.

There are many training and organizational changes that might be necessary to accommodate this, some examples:

1. Drivers would need to know 4-5 routes along a corridor in case they are expected to change routes. Currently, drivers may not be familiar with so many routes. If autonomous buses are available, they would have network wide information/awareness (basically like Cylons) and be able to serve any route. Shared autonomous vehicle fleet of varying sizes.

Other notes/comments:

1. Do buses still bunch when you have TSP? Assuming they run faster and are more likely to stay on schedule, they could still run \*too fast\*.
2. Bunching/holding strategies when you have TSP?
3. Crowd-based/ passenger load based TSP strategies? Holding and stop skipping strategies based on crowding? (Simon B. says most holding and skipping policies are based on schedule, not load)