Presentation outline

• Introduction and background
• Motivations and objectives
• Preliminary research
• Standard duty cycles
• Winnipeg transit buses data
• Data transformation
• Data analysis
• Ongoing research
Winnipeg transit buses

- Total 545 transit buses
- Service 88 routes
- All buses consume diesel
2011 New Flyer B/A D40 LFR
Winnipeg Transit 142
## Winnipeg transit routes (88)

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown spirit</td>
<td>3</td>
</tr>
<tr>
<td>Downtown routes</td>
<td>27</td>
</tr>
<tr>
<td>Express routes</td>
<td>29</td>
</tr>
<tr>
<td>Crosstown routes</td>
<td>5</td>
</tr>
<tr>
<td>Suburban routes</td>
<td>20</td>
</tr>
<tr>
<td>Dart routes</td>
<td>4</td>
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</tbody>
</table>
Route map

http://winnipegtransit.com/en/routes/60

http://winnipegtransit.com/en/routes/60

22/06/2011 2:19 PM

Winnipeg Transit Bus Data Analysis - Caixia Yang
On-board Bus Technology

In 2009 Winnipeg Transit completed the installation of GPS devices on all Transit buses.

Each bus in transit’s fleet has service schedule information loaded to an on-board computer that is linked to the Global Positioning Satellite system.

With this on-board technology, developed by Infodev Electronic Designers, each bus can determine where it is in relation to its assigned schedule and report schedule deviations to the Transit Control Center.
Real-Time Schedule Information

If a bus is running off schedule (either ahead of or behind schedule) the bus will send a signal to Transit’s real-time schedule server that updates its expected arrival time at all subsequent stops along the route. Each sign accesses this database once a minute so that it is providing the most up-to-date bus departure time for its location. This system ensures that “real time” information is provided to passengers waiting at one of these locations.

How to read the Display
Automatic passenger counting (APC)

To count traffic in buses we need to know two things:
• The number of persons boarding and exiting the bus.
• The exact location of the bus stop.
Basic system installation:

![Diagram of basic system installation]

Basic data collection method:

![Diagram of basic data collection method]
Any problem?

Yes!

- air pollution,
- greenhouse gas,
- noisy
- perception
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Why don’t use electricity?

Over 98% of all electricity generated by Manitoba Hydro in the Province of Manitoba is from renewable sources, primarily water power, and more recently through the emergence of wind power.
Objectives

- Duty cycles development
- Battery charge opportunities
- PHEV bus Simulation
- Fuel consumption estimation

The long-term vision is to develop a highly electrified transit bus system with opportunity and fast charging stations
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## Testing buses information

<table>
<thead>
<tr>
<th>Bus Id</th>
<th>Model</th>
<th>Year</th>
<th>Seat</th>
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<tbody>
<tr>
<td>401-430 (28) (Exclude 407,410)</td>
<td>D40LF</td>
<td>1998</td>
<td>39</td>
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<tr>
<td>570-589 (20)</td>
<td>D40LF</td>
<td>2003</td>
<td>38</td>
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<tr>
<td>671-699 (28)</td>
<td>D40</td>
<td>1994</td>
<td>48</td>
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<tr>
<td>911, 912 (2)</td>
<td>D30LF</td>
<td>1996</td>
<td>25</td>
</tr>
<tr>
<td>930, 932 (2)</td>
<td>D30LF</td>
<td>2001</td>
<td>25</td>
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</table>
## Summary on New Flyer buses

<table>
<thead>
<tr>
<th></th>
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<th>D40</th>
<th>D40i</th>
<th>D40LF</th>
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</thead>
<tbody>
<tr>
<td><strong>Seat</strong></td>
<td>26</td>
<td>46</td>
<td>42</td>
<td>38</td>
</tr>
<tr>
<td><strong>Standing</strong></td>
<td>23</td>
<td>38(26)</td>
<td>45(35)</td>
<td>35</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Diesel</td>
<td>Diesel</td>
<td>Diesel</td>
<td>Diesel</td>
</tr>
<tr>
<td><strong>CW (lbs)</strong></td>
<td>24,100</td>
<td>28,500</td>
<td>28,200</td>
<td>27,120</td>
</tr>
<tr>
<td><strong>GVL (lbs)</strong></td>
<td>150*49=7,350</td>
<td>150*84=12,600</td>
<td>150*87=13,050</td>
<td>150*73=10,950</td>
</tr>
<tr>
<td><strong>SLW (lbs)</strong></td>
<td>28,000</td>
<td>35,350</td>
<td>34,690</td>
<td>32,640</td>
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<tr>
<td><strong>GVW (lbs)</strong></td>
<td>31,450</td>
<td>41,100</td>
<td>41,380</td>
<td>37,620</td>
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<tr>
<td><strong>GVWR (lbs)</strong></td>
<td>31,200</td>
<td>39,600</td>
<td>40,090</td>
<td>32,640</td>
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</table>

**Fuel Economy**

<table>
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<tr>
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<th>D40</th>
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<th>D40LF</th>
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<tbody>
<tr>
<td><strong>Over all (MPG)</strong></td>
<td>5.16</td>
<td>4.02</td>
<td>4.14</td>
<td>3.24</td>
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<tr>
<td><strong>CED (MPG)</strong></td>
<td>4.06</td>
<td>2.92</td>
<td>3.39</td>
<td>2.63</td>
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<tr>
<td><strong>Arterial (MPG)</strong></td>
<td>5.13</td>
<td>3.52</td>
<td>3.83</td>
<td>3.08</td>
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<td><strong>Commuter (MPG)</strong></td>
<td>8.82</td>
<td>5.61</td>
<td>7.02</td>
<td>5.39</td>
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<tr>
<td><strong>20 Min Idle (GPH)</strong></td>
<td>0.82</td>
<td>0.75</td>
<td>0.41</td>
<td>0.84</td>
</tr>
</tbody>
</table>

**CW** - curb weight (bus weight including maximum fuel, oil, and coolant; but without passengers or driver)

**GVL** - gross vehicle load (150 lb for every designed passenger seating position, for the driver, and for each 1.5 sq ft of free floor space)

**SLW** - seated load weight (curb weight plus 150 lb for every designed passenger seating position and for the driver)

**GVW** - gross vehicle weight (curb weight plus gross vehicle load)

**GVWR** - gross vehicle weight rating
Vehicle load matters a lot!

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<thead>
<tr>
<th></th>
<th>D30 LF</th>
<th>D40</th>
<th>D40i</th>
<th>D40LF</th>
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<td>Seat</td>
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<td>46</td>
<td>42</td>
<td>38</td>
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<tr>
<td>Standing</td>
<td>23</td>
<td>38(26)</td>
<td>45(35)</td>
<td>35</td>
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<tr>
<td>Load(1)</td>
<td>150/24250</td>
<td>150/28650</td>
<td>150/28350</td>
<td>150/27270</td>
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<tr>
<td>Load(5)</td>
<td>750/24850</td>
<td>750/29250</td>
<td>750/28950</td>
<td>750/27870</td>
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<tr>
<td>Load(20)</td>
<td>3000/27100</td>
<td>3000/31500</td>
<td>3000/31200</td>
<td>3000/30120</td>
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<tr>
<td>Load(40)</td>
<td>6000/30100</td>
<td>6000/34500</td>
<td>6000/34200</td>
<td>6000/33120</td>
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<tr>
<td>Load(60) (49*)</td>
<td>(*) 7350/31450</td>
<td>9000/37500</td>
<td>9000/37200</td>
<td>9000/36120</td>
</tr>
</tbody>
</table>

Passenger load over vehicle weight shows the effect of passenger load on the performance of the bus, such as bus response to acceleration and break.

How about the effect of passenger load on fuel consumption?
Some operation time as evening, or holiday, only driver with a few passengers.
Bus driving speed distribution

- **Idling**
- **Acceleration**
- **Deceleration**
- **Cruise**
- **Creep**

**Speed distribution based on trips average speed**

- Very low speed
- Low speed
- Moderate speed
- High speed
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Note</th>
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<tr>
<td>Testing Bus Times</td>
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<tr>
<td>Number of tested Buses</td>
<td>80</td>
<td></td>
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<tr>
<td>Number of tested Routs</td>
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<td></td>
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<tr>
<td>Testing Days</td>
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<td>Max Daily Distance (km)</td>
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<td>Average Daily Distance (km)</td>
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<td>Testing Trips</td>
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<td>Max Trip Travel Distance (km)</td>
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<td>Average Trip Travel Distance (km)</td>
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<tr>
<td>Max Trip Stops</td>
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<tr>
<td>Max Load</td>
<td>89</td>
<td></td>
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<tr>
<td>Average Load</td>
<td>12</td>
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<tr>
<td>Number of events when 0&lt;t&lt;=5 Minutes</td>
<td>491908</td>
<td>97.33</td>
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<tr>
<td>Number of events when 5&lt;t&lt;=10 Minutes</td>
<td>9803</td>
<td>1.94</td>
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<tr>
<td>Number of events when 10&lt;t&lt;=15 Minutes</td>
<td>2728</td>
<td>0.54</td>
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<tr>
<td>Number of events when 15&lt;t&lt;=20 Minutes</td>
<td>760</td>
<td>0.15</td>
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<td>Number of events when 20&lt;t&lt;=25 Minutes</td>
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<td>0.024</td>
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<tr>
<td>Number of events when t &gt; 25 Minutes</td>
<td>84</td>
<td>0.016</td>
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<td>Number of events when t &gt; 20 Minutes</td>
<td>208</td>
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<tr>
<td>Number of events when t &gt; 15 Minutes</td>
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<td>0.19</td>
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<td>Number of events when t &gt; 10 Minutes</td>
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<td>0.73</td>
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<td>Number of events with passenger activity</td>
<td>505407</td>
<td></td>
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<tr>
<td>Parameter</td>
<td>Database average</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td>Number of trip</td>
<td>805</td>
<td></td>
</tr>
<tr>
<td>Average speed of the entire driving cycle in km/h</td>
<td>24.9</td>
<td></td>
</tr>
<tr>
<td>Average running speed in km/h</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td>Average daily traveled distance in km</td>
<td>204.8</td>
<td></td>
</tr>
<tr>
<td>Average acceleration of all acceleration phases in m/s²</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>Average deceleration of all deceleration phases in m/s²</td>
<td>-0.9</td>
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</tr>
<tr>
<td>Average length of a driving period in km</td>
<td>0.51</td>
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<tr>
<td>Average stops in 1 km</td>
<td>2</td>
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<tr>
<td>Time percentage of idling (zero velocity) in %</td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>Time percentage of acceleration: acceleration&gt;0.11m/s² in %</td>
<td>25.9</td>
<td></td>
</tr>
<tr>
<td>Time percentage of deceleration: acceleration &lt;-0.11m/s² in %</td>
<td>23.7</td>
<td></td>
</tr>
<tr>
<td>Time percentage of cruising (acceleration [-0.11,0.11] m/s², speed&gt;5m/s) in %</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td>Time percentage of creeping (acceleration [-0.11,0.11] m/s², speed&lt;5m/s) in %</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Time percentage of driving at very low speed bracket ( [0 20 ] km/h ) in %</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>Average speed in very low speed bracket [0 20 ] km/h</td>
<td>11.9</td>
<td></td>
</tr>
<tr>
<td>Time percentage of driving at low speed bracket ( [20 50 ] km/h ) in %</td>
<td>53.2</td>
<td></td>
</tr>
<tr>
<td>Average speed in low speed bracket [20 50 ] km/h</td>
<td>35.2</td>
<td></td>
</tr>
<tr>
<td>Time percentage of driving at moderate speed bracket ( [50 80 ] km/h ) in %</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>Average speed in moderate speed bracket [50 80 ] km/h</td>
<td>58.7</td>
<td></td>
</tr>
<tr>
<td>Time percentage of driving at high speed bracket ( [80 100 ] km/h ) in %</td>
<td>1.1</td>
<td></td>
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<tr>
<td>Average speed in high speed bracket [80 100 ] km/h</td>
<td>84.5</td>
<td></td>
</tr>
<tr>
<td>Percentage of driving time in congested route ( av&lt;15 km/h ) in %</td>
<td>98.3</td>
<td></td>
</tr>
<tr>
<td>Percentage of driving time in urban route ( 15=&lt;av&lt;30 km/h ) in %</td>
<td>1.6</td>
<td></td>
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<tr>
<td>Percentage of driving time in ultra_urban route ( 30=&lt;av&lt;45 km/h ) in %</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Percentage of driving time in highway route (av&gt;45 km/h ) in %</td>
<td>0.1</td>
<td></td>
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<tr>
<td>Maximum load</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Average load</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Average daily power consumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily energy consumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average daily fuel consumed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simulate bus dynamics, power required, fuel consumption, break regeneration, break performance

- different bus models – MCI, D30LF, D40, D40LF, D40I, D40LFR
- different load ranges – [0,5],[6-20],[21-40],[41-60]
- different driving cycles – real world and several standard driving cycles
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<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Average Speed</td>
<td>6.83</td>
<td>mph</td>
<td>10.99</td>
<td>kph</td>
</tr>
<tr>
<td>Std.Dev.Speed</td>
<td>7.34</td>
<td>mph</td>
<td>11.82</td>
<td>kph</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>25.30</td>
<td>mph</td>
<td>40.73</td>
<td>kph</td>
</tr>
<tr>
<td>Max. Accel. YCX</td>
<td>3.70</td>
<td>mph/s</td>
<td>1.65</td>
<td>m/s²</td>
</tr>
<tr>
<td>Min. Accel. YCX</td>
<td>-5.25</td>
<td>mph/s</td>
<td>-2.35</td>
<td>m/s²</td>
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<td>Max. Accel.</td>
<td>4.60</td>
<td>mph/s</td>
<td>2.06</td>
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<tr>
<td>Min. Accel.</td>
<td>-5.60</td>
<td>mph/s</td>
<td>-2.50</td>
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<td>Total Time</td>
<td>2178.00</td>
<td>s</td>
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<tr>
<td>Total Distance</td>
<td>4.13</td>
<td>mile</td>
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<td>Idle Time</td>
<td>786.00</td>
<td>s</td>
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<tr>
<td>Idle Periods</td>
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<td>Average Travel Distance</td>
<td>162.23</td>
<td>m</td>
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<td>Average Travel Time</td>
<td>33.95</td>
<td>s</td>
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<tr>
<td>Average Idling Time</td>
<td>19.17</td>
<td>s</td>
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<tr>
<td>Idling percentage</td>
<td>56.47</td>
<td>%</td>
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The Central Business District (CBD) Cycle

<table>
<thead>
<tr>
<th></th>
<th>Average Speed</th>
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<th>Max. Speed</th>
<th>Max. Accel. YCX</th>
<th>Min. Accel. YCX</th>
<th>Max. Accel.</th>
<th>Min. Accel.</th>
<th>Total Time</th>
<th>Total Distance</th>
<th>Total Distance</th>
<th>Idle Time</th>
<th>Idle Periods</th>
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<th>Average Travel Time</th>
<th>Average Idling Time</th>
<th>Idling percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.58 mph</td>
<td>8.36 mph</td>
<td>20.00 mph</td>
<td>2.40 mph/s</td>
<td>-4.50 mph/s</td>
<td>1.07 m/s²</td>
<td>-2.01 m/s²</td>
<td>1722.00 s</td>
<td>6.20 mile</td>
<td>9.98 km</td>
<td>345.00 s</td>
<td>43.00</td>
<td>232.14 m</td>
<td>32.02 s</td>
<td>8.02 s</td>
<td>25.05 %</td>
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<tr>
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<td>Max. Accel. YCX</td>
<td>Min. Accel. YCX</td>
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<td>Min. Accel.</td>
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<td>Total Distance</td>
<td>Idle Time</td>
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<td>Average Travel Time</td>
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<td>Idling Percentage</td>
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</tr>
<tr>
<td>Max. Speed</td>
<td>40.63 mph</td>
<td>65.41 kph</td>
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The New York Bus (NYBus) Cycle

- Duration: 600 s
- Maximum speed: 49.56 km/h (30.8 mph)
- Average speed: 5.94 km/h (3.7 mph)
- Average speed without stops: 17.11 km/h (10.6 mph)
- Maximum acceleration: 2.77 m/s$^2$
- Average acceleration: 1.17 m/s$^2$
- Number of stops per km: 11
- Total driving distance: 0.99 km
The Manhattan Bus Cycle

- Duration: 1089 s
- Maximum speed: 40.88 km/h (25.4 mph)
- Average speed: 11.0 km/h (6.8 mph)
The Orange County Bus Cycle

![Graph showing bus cycle speed over time]
EPA New York City Cycle (NYCC)

- Duration: 598 seconds
- Distance: 1.18 miles = 1.89 km
- Average speed: 7.1 mi/h = 11.4 km/h
- Maximum speed: 27.7 mi/h = 44.6 km/h
The Central Business District (CBD) Cycle

- Duration: 560 s
- Average speed: 20.23 km/h
- Maximum speed: 32.18 km/h (20 mph)
- Driving distance: 3.22 km
- Average acceleration: 0.89 m/s²
- Maximum acceleration: 1.79 m/s²
Presentation outline

• Introduction and background
• Motivations and objectives
• Preliminary research
• Standard duty cycles
• Winnipeg transit buses data
• Data transformation
• Data analysis
• Ongoing research
Original data

- Number of buses: 545
- Time period: from Jan. 2010 to Jan. 2010
- Models: MCI, D40, D30LF, D40LF, D40I, D40LFR
- Buses made of years: 1988-2010
- Manufactures: MCI, New Flyer Industries Inc
- Info in data: GPS with odometer reading
- Data size: 70 GB in binary format
  450 GB in xml format
Presentation outline

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Presentation outline

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• Data analysis
• Ongoing research
Info in data

- Busid
- Operation date and time
- Location of bus – GPS
- Odometer reading in meter

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</table>
Why need to find travel period?

- Values in column M are bus travel speeds in kph calculated directly from odometer reading
- Values in column N are bus travel speeds in kph calculated when consider travel period
How to find travel period?

- Travel time period based on date and time
- Convert travel time from “hh:mm:ss” to seconds
What happened when odometer reset?

- Bus travel speeds from odometer reading
- Re-correct travel speeds when odometer was reset
Sample speed profile

Speed vs time

- Speed vs time chart showing the speed profile over time.
- The x-axis represents time in seconds, ranging from 0 to 900.
- The y-axis represents speed in kph, ranging from 0 to 70.

Sample speed profile

100 200 300 400 500 600 700 800 900
0
10
20
30
40
50
60
70
time (second)
speed (kph)

22/06/2011 2:19 PM
Winnipeg Transit Bus Data Analysis - Caixia Yang
Speed profile based on one data file
Presentation outline

- Introduction and background
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- Ongoing research
Ongoing research

• Converting all 70 GB binary format data to usable data
• Cleaning converted bus operation data
• Based on insights of the finding problems, writing program on automatically data cleaning
• Duty cycle development for Winnipeg transit bus
• PHEV bus performance simulation
• Fuel consumption estimation
• Battery charging opportunities
• ???
Ongoing research

For vehicle simulation, a forward looking model is desired where a vehicle model responds to driver input commands to develop and deliver torque to the wheels similar to what it is in a real world scenario.

Above figure shows the interactions among the driver, the supervisory controller, the subsystems, and the vehicle model.

Source: [11]
Ongoing research

Figure 9-3. The Incident handling method.

Source: [12]
Reference


## Acknowledgements

<table>
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<tr>
<th>NSERC/Hydro Industrial Chair</th>
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<tbody>
<tr>
<td>Bill Menzies</td>
</tr>
<tr>
<td>Phil Wiwchar</td>
</tr>
<tr>
<td>Steven J. Brandson</td>
</tr>
<tr>
<td>Tony Dreolini</td>
</tr>
<tr>
<td>Paul Zanetel</td>
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<tr>
<td>Soheil Shahidinejad</td>
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<td>Ali Ashtari</td>
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Winnipeg Transit Bus Data Analysis - Caixia Yang
Thank you!

Questions?
BYD to supply city of Frankfurt with three electric eBUS-12s
China-based BYD has signed a letter of intent with the city of Frankfurt, Germany to supply the city with three of its battery-powered eBUS-12s and two DC charging stations by the end of the first quarter of 2012. The trio of electrified buses will serve as shuttles at Frankfurt Airport and along public transportation routes that lead to the city's Gateway Gardens.

BYD claims that its eBUS-12, with has a claimed range of 300 kilometers (186.4 miles), can travel further on a single charge than any other electric bus available today. At the core of the eBUS-12 is BYD's massive 324-kWh lithium iron phosphate battery pack that takes just over three hours to juice up with 100-kW charging equipment and approximately 30 minutes to refill with BYD's monstrous 600-kW proprietary rapid-charging system. That's a lot of juice.

The BYD eBUS has been used in Shenzhen and Changsha, China for several months now and some 200 more eBUS-12s will be delivered to the Universiade Shenzhen by the end of August.