Minimising negative externalities cost using 0-1 mixed integer linear programming model in e-commerce environment

Introduction

The impact of the Internet in the 21st century cannot be swept under the carpet. It has brought products close to customers; with a click customers can buy any products of their choice. Businesses are not left out; indeed, businesses making use of the Internet to sell their products are making abnormal profits (Xia & Zhang 2010). Lankford (2004) captures benefits for businesses using the Internet to sell their products as (1) fast speed to the market: quick response to changing market conditions, (2) less expensive: reduces business errors, decreases the use of labour and paper usage, provides better product tracking and delivery and cuts acquisition time; (3) highly flexible: custom interface between a company and its different clients and (4) shortening product delivery time. The first three benefits can be realised during the Internet business transaction but the last benefit involves other activities like transportation scheduling, product handling, efficient warehouse management, traffic management and others. Effective transportation scheduling or routing help reduce products delivery time (Ying & Dayong 2005). That notwithstanding, the immense environmental challenges and inconveniences created by petroleum products (gasoline and gas oil) used to power vehicles, vehicles parts disposal (e.g. dirty oil and car battery), vehicle weight impact on road and others need to be accounted for when scheduling products transportation (Cuevas-Cubria 2009; Knittel 2012; Santos et al. 2010). This article aims at developing a methodology that will most efficiently minimise negative externalities cost in e-commerce environments.

Researchers have applied different mathematical methods to minimise transport optimisation cost in e-commerce environments. Li, Wu and Zhang (2010) applied mutilate goals vehicle scheduling problem to investigate how time impacts product delivery in e-commerce logistics distribution. Their results emphasise that customers prefer to receive the products they ordered online mainly in the afternoon with a smaller width of time window. Customers’ preference of receiving products with smaller width of time mounts enormous pressure on transportation companies. Yang and Li (2013) used vehicle routing problem with time window (VRPTW) to study vehicle scheduling problem under e-commerce environment. They applied clustering analysis to analyse the problem and their simulation results revealed that VRPTW...
optimises cost better than the traditional vehicle routing problem. Dondo, Méndez and Cerdá (2009) developed a vehicle routing problem in supply chain management (VRP-SCM) to optimise complex distribution systems. Their VRP-SCM system allows two or more vehicles to visit a given location to perform pickup and delivery operations and vehicle routes may include several stops. Using a mixed integer linear programming (MILP), they solved the VRP-SCM problem which relies on a continuous time representation. Their approach provides a very detailed set of optimal vehicle routes and schedules to meet all product demands at minimum total transportation cost. Chen’s (2008) network convective distribution model helps to minimise logistics distribution problems in e-commerce, while Daly and Cui (2003) identified that transporting products along waterways in China creates serious problems which hinder e-logistics management in China.

Cuevas-Cubria (2009) compared externalities internalisation of greenhouse gases (GHG) and air pollution (AP) from biofuels and petroleum fuels. His results emphasise that biofuels produce less external cost and emission of GHG and AP compared to petroleum fuels. Further reduction of biofuel external cost and emission can be attained if critical attention is given to feedstock from which biofuels are produced. Santos et al. (2010) discussed the use of economic instruments to correct road transport externalities, giving relatively more weight to the problem of carbon emissions from road transport, as this is particularly challenging, given its global and long-term nature. They applied command-and-control (CAC) and incentive-based (IB) policies to address the problem of transport externalities. Their results indicate that IB policies are more cost effective than CAC. CAC policies are not efficient even in a perfect information scenario and IB policies do not impose any choices, but rather leave consumers and producers to make decisions according to their costs and benefits, preferences and constraints. In addressing these policies, government should put a price on the negative externalities, like a carbon tax or cap-and-trade policy created for petroleum fuels (Knittel 2012; Santos et al. 2010).

The papers reviewed have addressed (1) ways to minimise vehicles scheduling problems in e-commerce environments and (2) negative externalities costing. While most researchers focused on either minimising vehicles scheduling problems in e-commerce environments or negative externalities costing as separate entities, this research incorporates both externalities cost and scheduling in e-commerce environments. The 0-1 mixed integer linear programming (0–1 MILP) model was used to solve the optimisation problem and the results were further analysed using externality percentage impact factor (EPIF). The simulation result shows that (1) private cost and external cost surge up as oil marketing companies (OMCs) increase their demand for refined petroleum products (RPPs); however, EPIF ranges between 2% and 3%, (2) so far as RPPs are not distributed by automated pipelines but by vehicles, e-commerce transactions cannot reduce externality cost, (3) oil refinery companies (ORCs) can minimise production cost if they adopt close distance distribution strategy and (4) externality cost payment by industries necessitates further research to ascertain its fairness. The rest of the article is organised as follows: the ‘Statement of problem’ section defines the problem while the ‘Methodology’ section focuses on methodology: 0-1 MILP mathematical model and EPIF. The ‘Conclusion’ section deals with the simulation results and discussions. The final section concludes with the findings, future research and limitations of the article.

Statement of problem

In general, the channel by which OMCs’ procure RPP from ORC:

1. OMC places an order via the Internet.
2. ORC acknowledges receipt of the order and forwards it to their vehicle logistics department (Figure 1).
3. RPPs (gasoline, gas oil, LPG and kerosene) are stored at different sites (site A: gasoline, site B: gas oil, site C: LPG and site D: kerosene) to optimise storage capacity and to develop strategic usage of products at these sites.
4. The vehicle logistics department strategises ways to minimise negative externality cost to various filling stations as shown in Figure 2.

The heuristic distribution to the various filling stations encounters several problems like road networking, sequencing, scheduling and negative externalities among

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**FIGURE 1:** Oil marketing companies ordering refined petroleum products online.

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**FIGURE 2:** Oil marketing companies accessing and distributing refined petroleum products.
The 0-1 MILP model is used to solve the problem statement (Dondo et al. 2009; Uzar & Catay 2012). In developing the vehicle route plan to optimise the cost of negative externalities, these assumptions were taken:

- ORC owns sufficient vehicles to fulfil each OMC demand.
- ORC vehicle warehouses are located at vantage zones and the distance between warehouse and RPP storage sites are at most 10 km apart.
- Orders for RPPs are made through the Internet.
- The model does not account for vehicle delivery delay penalty costs, for example, traffic disruptions, stopover at previous stations, vehicle breakdowns and loading vehicle with petroleum product.
- ORC vehicles can access RPP from its storage site daily with no quantity limitations (in tons) and there are no queues at storage sites during product loading.
- A vehicle dispatched from a warehouse after completing its scheduling route cycle can be parked at any nearby warehouse and vehicles can be used to deliver any kind of RPP.
- The cost of ORC purchasing crude oil is not considered in the cost minimisation structure.
- Gasoline-powered vehicles are used to access and distribute RPP.
- Gasoline products used to power vehicles are not yet taxed by government since government will receive the cost minimisation structure.

These pollutants degrade the environment (thereby depleting the ozone layer), leading to negative health issues, short life span of roads, water pollution and curtailing the life of manpower in the country among others. This article addresses this problem by focusing on ways to minimise the negative externalities cost arising from the distribution of RPP by using both 0-1 MILP and EPiF methodologies.

The next paragraph touches on the 0-1 MILP mathematical model; refer to Appendix 1 for the nomenclature.

**Methodology**

This section discusses the 0-1 MILP model and EPiF. The 0-1 MILP mathematical model integrates the private and social cost to arrive at the optimum negative externality cost.

**Private cost**

The private cost is constructed by combining distances between warehouses and storage sites, storage sites and filling stations, filling stations (i.e. distance between filling station 1 and 2), RPP characteristics and demand and vehicle capacity and weight. The private cost objective function is:

\[
\min \sum_{v=1}^{n} \sum_{s=1}^{S} [(D_{\text{RPP}} \ast NV_{\text{RPP}} \ast S0.50) + (D_{\text{OMC}} \ast NV_{\text{OMC}} \ast S0.38)]
\]

\[
+ \sum_{v=1}^{n} \sum_{s=1}^{S} [(D_{\text{RPP}} \ast NV_{\text{RPP}} \ast S0.50) + (D_{\text{OMC}} \ast NV_{\text{OMC}} \ast S0.28)]
\]

\[
+ \sum_{v=1}^{n} \sum_{s=1}^{S} [(D_{\text{RPP}} \ast NV_{\text{RPP}} \ast S0.50) + (D_{\text{OMC}} \ast NV_{\text{OMC}} \ast S0.28)]
\]

\[
+ \sum_{v=1}^{n} \sum_{s=1}^{S} \{(FC_{v} \ast TNV_{s,v} \ast S0.28) + (DC_{v} \ast D_{\text{RPP}} \ast S0.28)\}
\]

\[[\text{Eqn 1}]\]

Subjected to:

\[
\sum_{v=1}^{n} W_{v} = 1 \forall v \in V
\]

\[[\text{Eqn 2}]\]

\[
\sum_{v=1}^{n} W_{v} = 1 \forall v \in V
\]

\[[\text{Eqn 3}]\]

\[
\sum_{v=1}^{n} J_{v} = 1 \forall p \in P
\]

\[[\text{Eqn 4}]\]

\[
\sum_{v=1}^{n} W_{v} \leq 1 \forall v \in V
\]

\[[\text{Eqn 5}]\]

\[
W_{v} = 1 \forall v \in V
\]

\[[\text{Eqn 6}]\]

\[
\sum_{v=1}^{n} W_{v} \leq 1 \forall v \in V, s \in S
\]

\[[\text{Eqn 7}]\]

\[
SV_{v} = 1 \forall v \in V, p \in P
\]

\[[\text{Eqn 8}]\]

\[
\sum_{v=1}^{n} \sum_{s=1}^{S} TV_{v} \leq \sum_{v=1}^{n} \sum_{s=1}^{S} TNV_{s,v} \forall v \in V, p \in P
\]

\[[\text{Eqn 9}]\]

\[
\sum_{v=1}^{n} TUL_{v} \geq \sum_{v=1}^{n} DEM_{v} \forall p \in P, \forall n \in P
\]

\[[\text{Eqn 10}]\]

\[
K \ast NV_{v} \geq TUL_{v} \forall p \in P, \forall v \in V, \forall n \in N
\]

\[[\text{Eqn 11}]\]

\[
\sum_{p=1}^{P} (TL_{p} \ast UC_{p} \ast V_{v} \ast s) \leq \sum_{p=1}^{P} (VC_{p} \ast V_{v} \ast s) \forall v \in V, \forall s \in S
\]

\[[\text{Eqn 12}]\]

\[
\sum_{p=1}^{P} (TL_{p} \ast UC_{p} \ast V_{v} \ast s) \leq \sum_{p=1}^{P} (WC_{p} \ast V_{v} \ast s) \forall v \in V, \forall s \in S
\]

\[[\text{Eqn 13}]\]
Constraint 14 ensures that most vehicles \( v \) loaded with RPPs can visit at least one filling station while constraints 15 and 16 capture the route constraint of vehicles \( v \) visiting exactly one filling station first \( n \) and exactly one filling station last \( n' \), respectively. Constraint 17 makes sure that every filling station \( n \) can at most be visited by a single vehicle during the planning horizon and the storage sites act as a pure RPP lifting site as captured by constraint 18. Constraints 19 and 20 state that a single filling station \( n \) can be visited first or last by vehicle \( v \). Finally, constraint 21 states that vehicle \( v \) must visit filling station \( n \) before visiting filling station \( n' \).

### Social cost

The social cost is restricted only to negative health issues (e.g. CO reduces the flow of oxygen in the bloodstream and HC produces ozone, ozone impacts on pulmonary function in children, asthmatics and exercising adults) (Parry, Walls & Harrington 2007) produced by gasoline-powered vehicles. Other external costs are vehicle involvement in road accident, vehicle weight impact on roads and the cost of disposing vehicles parts (e.g. faulty tires and dirty oil). These references (Lee 1993; Parry et al. 2007; US FHWA 1997) were used to estimate negative health, road accident, road maintenance and vehicle part disposal external cost. All the social costs were estimated in cent per miles but were converted into dollars per kilometre. The social cost objective function is shown below:

\[
\min \sum_{v \in V} \left( \sum_{n \in N} [D_{n, v} \cdot NV_{n, v}] \cdot 0.50 \right) + \sum_{v \in V} \left( \sum_{n \in N} [D_{n, v} \cdot NV_{n, v}] \cdot 0.28 \right) + \sum_{v \in V} \left( \sum_{s \in S} \sum_{n \in N} \left( F_{n, v} \cdot NV_{n, v} \right) \cdot 0.4 \right) + \sum_{v \in V} \left( \sum_{s \in S} \sum_{n \in N} \sum_{n' \in N} \left( F_{n', v} \cdot NV_{n', v} \right) \cdot \left( ULP_{v} + URA_{v} \right) \times 0.4 \right)
\]

[Eqn 1*]

Subjected to:

\[
LP_{v} \leq 1 \forall v \in V
\]

[Eqn 22]

\[
LP_{v} = 1 \forall v \in V
\]

[Eqn 23]

\[
RIC_{v} \leq 1 \forall v \in V
\]

[Eqn 24]

\[
PD_{v} \leq 1 \forall v \in V
\]

[Eqn 25]

\[
PD_{v} = 1 \forall v \in V
\]

[Eqn 26]
Simulation analyses and discussion

The developed 0-1 MILP model is simulated based on vehicle type and characteristics, distance between warehouse and storage sites, storage sites and filling stations, RPPs characteristics, RPP demand at filling, fixed cost and social costs. Distances between storage sites and filling stations were classified into three categories: (1) closer distance distribution (CDD) distance ranging from 1 km to 100 km, (2) mid distance distribution (MDD) distance covering 101 km – 250 km and (3) far distance distribution (FDD) distance from 251 km to 400 km. The Generalized Algebraic Modeling System (GAMS) software (Rosenthal 2014) 64-bits, CPLEX 24.3.3, and an Intel (R) Pentium (R) 987 CPU 1.50 GHz, 4.00 GB RAM computer were used to analyse five different scenarios to ascertain the robustness of the 0-1 MILP model and Tables 1–7 exhibit the assumed parameters.

Scenarios

The robustness of the 0-1 MILP model for private and social cost was tested using 15 scenarios. This was obtained by taking a combination of four (i.e. 4C1, 4C2, ..., 4C4) because four RPPs were to be scheduled. For example, the private and social costs of scheduling RPPs under CDD or MDD or FDD strategy for gasoline, gas oil, LPG, gasoline and gas oil, LPG and kerosene, and gasoline, gas oil and kerosene were analysed.

Per the assumption taken, ORC’s may satisfy OMCs’ demands for single (gasoline, LPG and kerosene) RPP to be accessed and distributed to five filling stations by using a single vehicle, with the exception of gas oil where two vehicles are required. Besides, more vehicles are needed to meet OMCs’ demand increments. As the number of vehicles used to access and distribute RPP increases private cost, external cost due for government increases per the distance distribution strategy applied. The lowest and highest private cost for CDD, MDD and FDD strategies are $2786.80 – $58112.35, $8855.75 – $173970.35 and $14427.75 – $267420.37, respectively, and for that of social cost and external cost (refer to Appendix 2 and Figure 3). That notwithstanding EPIF for all the distance distribution strategies lies between 2% and 3%. The lowest EPIFs for CDD, MDD and FDD are 2.14%.
2.22% and 2.18% and the highest for these strategies are 2.83%, 2.98% and 2.92%, respectively (refer to Appendix 2 and Figure 4).

From the simulation results as OMCs’ demand for RPP increases, the total number of vehicles needed to access and distribute RPPs increases, which increases inhumane gas pollutants in the atmosphere, shortens the lifespan of tarred road, increases vehicle spare-parts replacement in the long run and delays RPPs to various filling stations. These negative repercussions justify why externality cost keeps rising with increase in OMCs’ demands. Although external cost keeps increasing, it is within government threshold, but if government changes its threshold ORC may end up paying high (less) external cost. The high external cost increases ORC operation cost, and this is mostly passed on to OMCs that further offload it to customers, that is, customers complaining about buying RPP at high cost. The external cost helps government to raise funds to clean the environment. However, government can improve its taxes on externality if it ensures effective internalisation of negative external activities generated by OMC’s at various filling stations. External cost in both the short and long run empowers government to achieve its goal of cleaning the environment. Although RPPs daily usage creates a lot of environmental pollution, its alternative replacement in the near future may be extensively difficult due to its well-established usage in the world.

Besides, no matter the distribution strategy employed by ORC, external cost remains almost the same. The main contributing factor for this phenomenon is that in the short run as the total number of vehicles used to access and distribute RPPs increase body part pollution is rare. Meaning ORC management may recover their capital investments on vehicles and also free it from buying vehicle spare-parts. The closer distance distribution strategy (CDD) yields smaller amounts of private and external cost compared to the other strategies. Suggesting distribution RPP to filling stations closer to each other reduces cost and improves ORC efficiency. Furthermore, the EPIF enlightens management that any distribution strategy employed results in almost equal amounts of external cost: meaning a particular or a mixture of strategies used to distribute RPP may yield the same negative externality cost. In addition, ordering RPPs via the Internet does not reduce external cost so far as accessing and distribution are fulfilled by vehicles. ORC may enjoy lesser external cost if they distribute RPPs by automated pipeline, which is very expensive in its initial stage. In so doing, they pay less external cost to cover burst, cracked or faulty pipelines. In addition, comparing the external cost computed in this article and what ORC’s and OMC’s actually pay as external cost to government raises the question, ‘are ORC or OMCs paying less, fair or excess external cost?’

### TABLE 3: Distance between warehouse and storage sites (km).

<table>
<thead>
<tr>
<th>Warehouse</th>
<th>Storage sites</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>-</td>
<td>8.8</td>
<td>7.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>W2</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>-</td>
</tr>
</tbody>
</table>

### TABLE 4: Refined petroleum product characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Gasoline</th>
<th>Gas oil</th>
<th>LPG</th>
<th>Kerosene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>2.86</td>
<td>2.03</td>
<td>1.03</td>
<td>3.80</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0.015</td>
<td>0.020</td>
<td>0.005</td>
<td>0.030</td>
</tr>
</tbody>
</table>

### TABLE 5: Distance between storage site and filling stations (km).

<table>
<thead>
<tr>
<th>Storage site</th>
<th>Closer distance distribution (CDD)</th>
<th>Mid distance distribution (MDD)</th>
<th>Far distance distribution (FDD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F1</td>
<td>F2</td>
<td>F3</td>
</tr>
<tr>
<td>A</td>
<td>62</td>
<td>22</td>
<td>99</td>
</tr>
<tr>
<td>B</td>
<td>19</td>
<td>43</td>
<td>92</td>
</tr>
<tr>
<td>C</td>
<td>65</td>
<td>88</td>
<td>17</td>
</tr>
<tr>
<td>D</td>
<td>29</td>
<td>72</td>
<td>7</td>
</tr>
</tbody>
</table>

### TABLE 6: Distance between filling stations (i.e. the distance between filling station 1 and 2 per km).

<table>
<thead>
<tr>
<th>Filling station</th>
<th>Closer distance distribution (CDD)</th>
<th>Mid distance distribution (MDD)</th>
<th>Far distance distribution (FDD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F1</td>
<td>F2</td>
<td>F3</td>
</tr>
<tr>
<td>F1</td>
<td>0</td>
<td>27</td>
<td>39</td>
</tr>
<tr>
<td>F2</td>
<td>27</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>F3</td>
<td>39</td>
<td>55</td>
<td>0</td>
</tr>
<tr>
<td>F4</td>
<td>54</td>
<td>89</td>
<td>44</td>
</tr>
<tr>
<td>F5</td>
<td>100</td>
<td>91</td>
<td>98</td>
</tr>
</tbody>
</table>

### TABLE 7: Filling stations demand of refined petroleum products (m³).

<table>
<thead>
<tr>
<th>Refined petroleum products</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>1400</td>
<td>870</td>
<td>1650</td>
<td>1250</td>
<td>1050</td>
</tr>
<tr>
<td>Gas oil</td>
<td>1400</td>
<td>1550</td>
<td>1370</td>
<td>1750</td>
<td>1800</td>
</tr>
<tr>
<td>LPG</td>
<td>1110</td>
<td>1280</td>
<td>1300</td>
<td>1450</td>
<td>1150</td>
</tr>
<tr>
<td>Kerosene</td>
<td>1040</td>
<td>1350</td>
<td>1050</td>
<td>1300</td>
<td>1500</td>
</tr>
</tbody>
</table>
any minute changes may impact the results. Future research works can be conducted by expanding the 0-1 MILP assumptions, parameters and externality assumptions, and mixing the distribution strategies.

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### Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

### Authors’ contributions

This work was carried out in collaboration between all authors. A.T. designed the study, wrote the literature and provided support by means of simulation analysis. All authors read and approved the final manuscript.

### References


Appendix starts on the next page →
Appendix 1: Nomenclature

Subscripts

\( w \) warehouse
\( s \) refined petroleum product storage site
\( v, v' \) vehicles
\( p, p' \) products
\( n, n' \) nodes

Sets

\( W \) sets of warehouses
\( S \) sets of storage sites
\( V \) sets of vehicles
\( P \) sets of refined petroleum products (gasoline, gas oil, LPG, kerosene)
\( N \) sets of filling stations

Parameters

\( VC_v \) vehicle \( v \) volume capacity
\( WC_v \) vehicle \( v \) weight capacity
\( FC_{vp} \) fixed cost for vehicle \( v \) operation (i.e. drivers’ fees, cost of fuel, etc.)
\( D_{W1SB} \) distance between warehouse 1 and storage site B
\( D_{W1SC} \) distance between warehouse 1 and storage site C
\( D_{W2SA} \) distance between warehouse 2 and storage site A
\( D_{W2SD} \) distance between warehouse 2 and storage site D
\( NV_{W1SB} \) number of vehicles dispatched from warehouse 1 to storage site B
\( NV_{W1SC} \) number of vehicles dispatched from warehouse 1 to storage site C
\( NV_{W2SA} \) number of vehicles dispatched from warehouse 2 to storage site A
\( NV_{W2SD} \) number of vehicles dispatched from warehouse 2 to storage site D
\( TNV_{W12} \) total number of vehicles dispatched form warehouse 1 and 2
\( D_{NN} \) distance between filling station \( n \) and \( n' \) in kilometres
\( TNV_{vs} \) total number of vehicles \( v \) at RPP storage sites \( s \)
\( DEM_{pn} \) demand of refined petroleum products \( p \) at various filling stations \( n \)
\( DC_{pn} \) unit distance cost for delivery refined petroleum products \( p \) using vehicle \( v \)
\( TL_{pvs} \) total amount of refined petroleum product \( p \) loaded on vehicle \( v \) at storage site \( s \)
\( TUL_{pvn} \) total amount of refined petroleum product \( p \) unloaded at filling station \( n \) from vehicle \( v \)
\( UV_p \) unit volume of refined petroleum product \( p \)
\( UW_p \) unit weight of refined petroleum product \( p \)
\( ULP_{vp} \) unit cost of local pollution emitted by vehicle \( v \) accessing and distributing RPP \( p \)
\( URA_{vp} \) unit cost of road accident vehicle \( v \) is involved in during RPP \( p \) accessing and distribution
\( URD_{vp} \) unit cost of road damage caused by vehicle \( v \) accessing and distributing RPP \( p \)
\( UVD_{vp} \) unit cost of disposing vehicle \( v \) damaged parts when RPP \( p \) are access and distributed
\( K \) upper boundary of constraint

Binary variable

\( W_v \) set of vehicles \( v \) housed at oil refiner company warehouse
\( V_{vs} \) variable denotes vehicle \( v \) is used for delivering refined petroleum products \( p \)
\( LFS_{nv} \) variable determines that filling station \( n \) is the last filling station vehicle \( v \) visited
\( FFS_{nv} \) variable determines that filling station \( n \) is the first filling station vehicle \( v \) visited
\( F_{svn} \) variable denotes vehicle \( v \) visited filling station \( n \) after visiting filling station \( n' \)
\( NV_{nv} \) variable determines that first filling station \( n \) is visited by vehicle \( v \)
\( NV_{nv} \) variable determines that last filling station \( n' \) is visited by vehicle \( v \)
\( W_{vs} \) variable denotes number of vehicles \( v \) dispatched to RPP storage site \( s \)
\( SV_{ps} \) variable denotes vehicle \( v \) has been served with RPP \( p \) at storage site \( s \)
\( W_{v12} \) variable denotes vehicle \( v \) was dispatched from warehouse 1 and parked at warehouse 2 after completing its delivery cycle
\( W_{v21} \) variable denotes vehicle \( v \) was dispatched from warehouse 2 and parked at warehouse 1 after completing its delivery cycle
\( J_v \) variable denotes vehicle \( v \) can be used to deliver any kind of RPP \( p \)
\( LP_v \) variable denotes local pollution caused by vehicle \( v \) per kilometres
\( RA_v \) variable indicates vehicle \( v \) involvement in road accident
\( RIC_v \) variable symbolises vehicle \( v \) weights during accessing and distributing of RPP contributes to wear and tear of tarred roads
\( PD_v \) variable indicates how often vehicle \( v \) body parts are replaced
\( DD_v \) variable denotes the delay cost of vehicle \( v \) involved in an accident
## Appendix 2

<table>
<thead>
<tr>
<th>Number of vehicles</th>
<th>Scenario</th>
<th>PC (CDD)</th>
<th>SC (CDD)</th>
<th>NE (CDD)</th>
<th>EPIF (CDD) (%)</th>
<th>PC (MDD)</th>
<th>SC (MDD)</th>
<th>NE (MDD)</th>
<th>EPIF (MDD) (%)</th>
<th>PC (LDD)</th>
<th>SC (LDD)</th>
<th>NE (LDD)</th>
<th>EPIF (LDD) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Gl)</td>
<td>3167.80</td>
<td>3236.06</td>
<td>68.26</td>
<td>2.15</td>
<td>9137.80</td>
<td>9340.77</td>
<td>202.97</td>
<td>2.22</td>
<td>15093.80</td>
<td>15423.40</td>
<td>329.60</td>
<td>2.18</td>
</tr>
<tr>
<td>1</td>
<td>(L)</td>
<td>2867.75</td>
<td>2929.24</td>
<td>61.49</td>
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PC, private cost; SC, social cost; NE, negative externality; EPIF, externality percentage impact factor.