Modelling Freight Transportation Impacts of the Gulf Cooperation Council Region using GIS

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Abstract. Freight transportation is a key element in economic growth and the development of countries. Linking freight lines between Gulf Cooperation Council (GCC) countries (specifically Kuwait, Saudi Arabia, Bahrain, United Arab Emirates and Oman) will increase revenues, improve infrastructure asset efficiency and generate employment. Shipping and transport industries endure continuous changes and transformations in response to technological developments and changes in world trade. Significant amounts of documentation, research papers as well as technical and economic reports are available in literature that details ways in which these industries respond to and meet the needs of shippers and consumers. Information and data are valuable assets in providing a basic understanding and base knowledge of the different types and methods of shipping options, as well as the impacts of different transportation modes. In this paper, possible environmental impacts will be discussed, including air quality, noise levels and vibration. In addition, safety factors such as fatalities and accidents will be incorporated into discussions on mode selection. A GIS model was implemented and a case study was created to assess these impacts, estimate damage costs as well as discuss concerns with logistics and mode selection. Finally, possible mitigation measures to manage environmental and safety concerns will be proposed. Based on the analysis and results, more work on environmentally sustainable models and designs need to be implemented to mitigate impacts and to ensure that the environment and quality of life can be preserved. Incentivizing shifts from truck to rail or to intermodal systems is key for shippers’ participation in reducing environmental and societal impacts. Encouraging shippers to change their mode selection can relieve congestion and lower accident rates.

1. Introduction
Freight transportation is a key element in economic growth and the development of countries. Linking freight lines between Gulf Cooperation Council (GCC) countries (specifically Kuwait, Saudi Arabia, Bahrain, United Arab Emirates and Oman) will increase revenues, improve infrastructure asset
efficiency and generate employment. To implement such linkages using railways or road networks, transport modes need to be assessed in terms of impacts that are significant including environmental issues (specific issues discussed in this paper are air quality, noise and vibration) as well as socio-economic activities in both urban and residential areas. Policy makers and government bodies responsible for rules and regulations on freight transport should take these considerations into account, as such freight line linkages are sure to have an impact on those inhabiting and visiting these areas. Therefore, minimizing these affects in conjunction with environmental and sustainability goals in the region should be central in the assessment process. Shippers should additionally revisit how environmental and socio-economic impacts can be included in their logistic plans for freight infrastructure that is developed as a result of linkages between these GCC countries.

2. Literature Review

Side effects of freight transport operations should be considered because each mode has some side effects to society and potential greater effects to the world at large. Earlier work in 1999 shows the assessment of the external cost and impact of freight shipment by truck, including all calamities such as mortalities, damages, property impairment and unrecovered costs linked with the provision, operation and maintenance of public roads and bridges. Following in 2001, researchers discussed the external costs of rail and truck freight transport, with consideration given to air pollution, greenhouse gases and noise influences as the factual costs to society [2], [3]. It was stated that external costs should be completely acknowledged and clear when transportation strategies are designed. Additional research in 2002 studied the external costs only, and analyzed that the external effects of interurban freight transportation provide an approximation of the chief social costs they inflict upon the population. To estimate the whole financial and social costs of transport by the whole foremost modes, it is often compulsory to calculate costs per vehicle-kilometre [4]. According to a study in 2007, the external costs of road freight transportation in the U.K. were found to be absorbed by duties and taxes paid by truck users such as road tolls and vehicle excise duty. It was emphasized that road freight transportation systems play a critical role in the development of the British economy and preservation of social well-being. The same report provided efficient estimates of the whole external charges of road freight transportation in the U.K. by taking into consideration three types of costs. These were the environmental charges comprising climate change, air pollution (including noise) and accident costs. It was anticipated that if the government were to deliver extra road space and use additional modes to discharge traffic congestion, congestion charges would be reduced, so that taxes are minimized by external costs being minimized [5].

An evaluation of CO₂ releases for truck-only and rail-based intermodal freight schemes in Europe found that rail-based intermodal freight transportation systems were more environmentally friendly than truck-only freight schemes, particularly for long-distance delivery and in terms of CO₂ emissions. The same report assessed the input and output of emissions for three different kinds of freight transportation modes: trucks, diesel trains and electric trains (that produce emissions from power plants involved in manufacturing), using mathematical equations for each case [6]. In 2012, another study focused on the emissions and noise produced by freight transportation modes and their respective impacts to the environment [7], [8]. In conclusion, all freight impact factors can affect the world at large, and researchers have been investigating and discussing these matters for the last few decades. In the context of this paper, a limited study has been conducted on freight transportation and its impact on the Arabian Gulf area. This area has experienced rapid growth in transportation, construction, and manufacturing, and importantly, the oil industry has had a significant impact on the entire region. The authors will discuss specifics on transport impacts, and the subsequent development of a GIS model that can be used as an efficient tool for optimization and transport design system strategies in future.

3. Research Methodology

Various deficiencies were found after conducting a comprehensive literature review to study the impact for goods movement to assess the viability of using both railway and trucking systems. As a part of this
study components, data were collected from different sources of different countries within the GCC region that influence the model selection analysis to develop an economical framework for the subsequent creation of a valuable tool for future development of freight transport design and strategies. This framework can aid in informing decision-making and as well as shape the implementation of policies and regulations promoting sustainable development and service delivery.

A geographic information system (GIS) ModelBuilder will then be used to run multiple geoprocessing tools along with their various parameters to develop the Impact Cost Analysis model to discuss the intermodal options and other shipping scenarios. Figure 1 shows the Impact Cost Analysis framework that has been implemented and to be considered for analysis and calculations.

![Figure 1. Impact Cost Analysis (LCCA) Framework.](image)

An important objective of this study is to develop an economic framework and useful tool that can aid policy makers’ decisions, where the most economically appropriate and reliable freight mode can be more readily apparent as well as provide guidance in evaluating the outcomes of creating and revising rules and regulations.

4. Freight Transportation Impacts and External Cost Overview

As noted previously, freight transport can affect the world at large through greenhouse gas pollution that arises, can contribute to global warming and can generate other health problems. Pollution costs can be estimated based on exposure to transport modes [9]. Exhaust emissions and electric rail generation plants produce different components of air pollutants including carbon monoxide (CO), nitrogen oxide (NOX), hydrocarbons (HC), carbon dioxide (CO₂) and other toxic substances that can affect the health of humans as well as plants and animals, which has subsequent impacts on food systems and eco-systems. Table 1. shows the main pollutant volume produced when using freight trucks and railways by tonnage carried per km.

| Pollutants | Freight Rail (g/ton.km) | Freight Truck (g/tons.km) |
|------------|-------------------------|----------------------------|
| CO₂        | 38.296                  | 72                         |
| NOX        | 0.834                   | 1.1                        |
| CO         | 0.148                   | 1.5                        |
| PM         | 0.018                   | 0.1                        |
| HC         | 0.039                   | 0.15                       |
CO₂ is the most problematic air pollutant that is a result of greenhouse gas emissions from land freight transportation. About 27% of greenhouse gas emissions are a result of transportation systems as shown in Figure 2.

![Figure 2. U.S. greenhouse gas emission in 2013, EPA [11].](image)

To prove how serious this issue is, recently in June 2017, Google Maps implemented a program that monitors the air quality of roads and adjacent areas using sensors. These sensors can provide data and a visual depiction of the amounts of NO, NO₂, black carbon and all pollutants that are a result of vehicle exhaust. The program can also monitor environmental changes as well, where conditions may improve or diminish. Figure 1 shows the amount of pollution and air quality in Oakland, California based on Google Maps’ new program. As shown in Figure 3, various parts of the network need to be analyzed in terms of the effects on surrounding communities as well as finding solutions to minimize these impacts.

![Figure 3. Air quality Google Maps snap shots, Oakland, California [12].](image)

To discover the volume and the concentration of CO₂ around the world, Figure 4 shows the CO₂ time series 1990-2014 per capita for all regions in the world.
Figure 4. CO$_2$ time series 1990-2014 per capita for world region/country, Emissions Database for Global Atmospheric Research [13]

From the above figure, it is very clear that the GCC region has a serious issue in regards the concentration of CO$_2$, and this demonstration of these levels indicates that action needs to be taken to minimize the amount of pollution being produced. Figure 5 demonstrates the effects of freight rail and its corresponding facilities to air quality and the surrounding environment.

An additional societal impact as a result of freight transportation is noise and vibration. Running railways and heavy trucks within an urban area will undoubtedly cause disturbances within neighbourhoods. Such disturbances can be significant in rural and less populated areas as well. The level of noise is a function of traffic volume, distance to the noise, percentage of trucks or rail and availability of noise barriers [14]. Compared to trucking systems, railways can be considered to be quieter than the equivalent volume of trucks carrying the same amount of tonnage. Noise intensity can have a negative impact on health, including symptoms such as headaches, sleep disturbance and other hearing problems especially when freight passes through a residential area as shown in Figure 6.

The intensity is based on the type of locomotives or trucks, the amount of traffic per day and the system used (including wheel friction, horns and the number of running engines). It has been reported that railways produce about 82 dBA at a distance of 15m from the rail track centreline [10], which is close to inflicting hearing loss damage. Figure 7 shows the effects of prolonged exposure for different noise levels as per the Occupational Safety and Health Administration (OSHA). In terms of vibration, it can result in generating damages to soil and the structures surrounding the passing areas.
Figure 6. Freight rail passes by a residential area in Saudi Arabia [14].

Figure 7. Freight rail passes by a residential area in Saudi Arabia [14].

The last factor to be discussed is safety. The number of accidents and fatalities rates per capita per vehicle can also impact communities and shipping mode choices. Accident costs can be quantified based on the number of injuries and fatalities of using that mode per year [17]. As per data from research conducted for a Saudi Arabian National Transportation Study in 2008, Table 2 presents the accident rate with a sample of European countries compared with Saudi Arabia.

Table 2. Accident data with a sample of European countries compared with Saudi Arabia [18]

| Country     | Fatalities per 100,000 population | 10,000 vehicles |
|-------------|----------------------------------|-----------------|
| Sweden      | 6.1                              | 1.35            |
| UK          | 6.3                              | 1.28            |
| Holland     | 7.6                              | 1.85            |
| Finland     | 7.9                              | 1.83            |
| Switzerland | 8.7                              | 1.62            |
| Germany     | 10.7                             | 2.02            |
| Ireland     | 12.6                             | 4.04            |
| Austria     | 12.7                             | 2.56            |
| France      | 14.7                             | 2.78            |
| Saudi Arabia| 15.9                             | 20.82           |
All of the above factors demonstrate that Saudi Arabia has a very serious susceptibility for accidents that needs to be analysed in order to be able to reduce damages and fatalities associated with accidents with the aim of increasing safety measures overall.

5. GCC Freight Transportation Impact
Land freight commodities can be transported using railways, trucking or intermodal systems, and possible impacts can arise in the form of pollution, noise, vibration and accidents. Each factor can be evaluated based on societal suffering or losses of resources. The data used in this paper were collected from different agencies and authorities in the GCC member countries, including the Abu Dhabi Municipality, Presidency of Meteorology and Environment in Saudi Arabia and the Saudi Railways Organization. In order to recover from particular impacts, external cost was estimated and expressed in US dollars. Based on the available data, some factors were scaled to the GCC countries to complete the modelling exercise. Tables 3 and 4 show the external costs of transport by mode including accidents, noise and air pollution costs [10].

Table 3. Air pollution and noise freight transportation costs [10]

| Freight Modes | Cost per 1,000 tonne-kms ($ US) |
|---------------|---------------------------------|
| Noise and vibration | Truck $7.49, Rail $5.10 |
| Air pollution | $22.15, $6.86 |

Table 4. Accident factor freight transportation costs [10]

| Freight Modes - Cost per 1,000 tonne-kms ($ US) |
|-----------------------------------------------|
| Country | Truck | Rail |
| Bahrain | $19.92 | $1.30 |
| Oman | $11.95 | $1.30 |
| UAE | $9.96 | $1.30 |
| Kuwait | $19.92 | $1.30 |
| Saudi Arabia | $19.92 | $1.30 |

Urban distances have only been considered in calculating noise factors, while other impacts were considered for the whole distance using the following equation:

\[
\text{Average Impact cost} = \frac{(\text{Impact cost} \times \text{Distance driven in a country})}{\text{Total shipping distance}} \quad (1)
\]

Where; Average Impact Cost: Truck / Rail (US$/ton-km), Impact Cost: (US$/ton-km), Distance driven in a country (km), Total shipping distance (km).

6. Modelling Analyses and Results
To discuss such impacts, a GIS model was developed. Figure 8 shows a snapshot from the GIS model that has been implemented for the GCC region. This GIS model can be used by shippers to figure out the share they should pay per shipment to recover the impact costs, as well as aid them in selecting alternative routes to minimize the impact of freight transport around urban, residential and rural areas. For that purpose, two different case studies have been developed and analysed.
The first case study involved the total life cycle cost, impact cost and pollution produced using railway and trucking systems. Various origins and destinations had been randomly selected to examine the model and to achieve the objectives of this paper as shown in Figure 9. Table 5 summarizes the results of shipping a container using different tonnage between three origins and destinations.

As shown in Table 5, the overall impact cost of using the intermodal mode is less than using a trucking system. It is worth mentioning that when the mode passes through an urban area, the noise factor will be an overall count within the total distance, which illustrates that there is a higher noise cost when shipping between Abu Dhabi and Muscat.

As mentioned earlier, emissions have two distinct impacts at local and global levels. At the local level, they are a source of air pollution, thereby reducing air quality. While at the global level, emissions can contribute to climate change. Both local and global level air pollution can result in the deterioration in human health, damage to property, declines in crops and agricultural production, increases of overall annual temperatures, rising sea levels, coastal flooding increases, stresses on wildlife (thereby impacting eco-systems and the environment), as well as other economic impacts.

In order to decrease the pollution severity level that arises from freight transportation, alternative origins and destinations have been selected to examine the pollution produced as a second case study as shown in Figure 9.
in Figure 10. This case study can be considered a valuable tool for decision makers to build policies, rules and regulations. Table 6 and Table 7 show the amount of CO$_2$ produced by using rail and trucking systems for the two selected routes.

**Table 5.** Results of shipping a container using different tonnage between three origins and destinations

| Distance | Origins and Destinations O/D original | Impact Cost - Noise | Impact Cost - Accident | Impact Cost - Pollution |
|----------|---------------------------------------|---------------------|------------------------|------------------------|
|          |                                       | Truck               | Intermodal             | Truck                  | Intermodal             | Truck | Intermodal |
| Short    | Jubail/ Dammam                         | 23                  | 46                     | 69                     | 23                    | 46           | 69           | 53.1               | 106.2            | 159.3             | NA                | NA                | NA                |
| Medium   | Abu Dhabi / Muscat                     | 67.8                | 135.7                  | 203.5                  | 62.8                  | 129.3            | 196.5        | 144.9             | 289.9            | 434.9             | 36.2              | 75.8              | 116.2             |
| Long     | Riyadh/Madinah                         | 58.1                | 116.1                  | 174.1                  | 46.3                  | 94.1             | 141.1        | 435.6             | 871.2            | 1306.9            | 179.1             | 365.8             | 548.7             |

**Figure 10.** Example of original and alternative shipping routes between Jubail and Dammam city
Table 6. CO₂ amounts produced by using rail and trucking systems using the original routes

| Distance | Origins and Destinations O/D | Pollution produced (CO₂ Ton) |  |
|----------|-------------------------------|-------------------------------|---|
|          | Original route                |                              |   |
|          | Truck                         | Intermodal                   |   |
| Short    | Jubail/ Dammam                | 211639.1                     | 423278.2 | 634917.2 |
| Medium   | Abu Dhabi / Muscat            | 1014278                      | 2028555 | 3042833 |
| Long     | Riyadh/Madinah                | 1735733                      | 3471467 | 5207200 |

Table 7. CO₂ amounts produced by using rail and trucking systems using the alternative routes

| Distance | Origins and Destinations O/D | Pollution produced (CO₂ Ton) |  |
|----------|-------------------------------|-------------------------------|---|
|          | Alternative route             |                              |   |
|          | Truck                         | Intermodal                   |   |
| Short    | Jubail/ Dammam                | 163305                       | 326611 | 489917 |
| Medium   | Abu Dhabi / Muscat            | 850190                       | 1679309 | 2518964 |
| Long     | Riyadh/Madinah                | 1582632                      | 3170654 | 4720754 |

As shown in the above tables, alternative routes produce less CO₂ emissions for the same origins and destinations over all distances. At the same time, noise impact will be increased using alternative routes since it passes by urbanized areas. Table 8 shows the noise cost for both alternative and original shipping routes. However, the total shipping cost of the alternative routes remains less than the total shipping cost of the original routes as shown in Table 9.

Table 8. Noise cost for original and alternative shipping routes

| Distance | Origins and Destinations O/D | Noise Cost – Trucking system |  |
|----------|-------------------------------|------------------------------|---|
|          | Original route                | Alternative route            |   |
|          | Truck                         |                              |   |
| Short    | Jubail/ Dammam                | 23.5889                      | 47.1779 | 70.7668 | 32.8 | 65.5 | 98.3 |
| Medium   | Abu Dhabi / Muscat            | 67.8298                      | 135.66 | 203.489 | 132.7 | 262.1 | 393.1 |
| Long     | Riyadh/Madinah                | 58.0386                      | 116.077 | 174.116 | 105.8 | 212.1 | 315.7 |

Table 9. Total shipping cost for original and alternative shipping routes

| Distance | Origins and Destinations O/D | Total Shipping Cost – Trucking system |  |
|----------|-------------------------------|----------------------------------------|---|
|          | Original route                | Alternative route                       |   |
|          | Truck                         |                              |   |
| Short    | Jubail/ Dammam                | 454.8                                  | 909.7 | 1364.5 | 413.7 | 827.4 | 1241.1 |
| Medium   | Abu Dhabi / Muscat            | 1282.1                                 | 2564.2 | 3846.3 | 1183.6 | 2342.9 | 3514.4 |
| Long     | Riyadh/Madinah                | 2075.3                                 | 4150.7 | 6225.9 | 1963.8 | 3933.6 | 5861.3 |

As a result, the analysis of the two case studies show that using the developed GIS life cycle analysis model is a useful tool to select the most reliable route based on the total shipping, impact cost and the amount of pollution produced.
7. Conclusions

Based on the analysis and results, more work on environmentally sustainable models and designs need to be implemented to mitigate impacts and to ensure that the environment and quality of life can be preserved. Over long periods of time, environmental, safety and noise pollution can have significant impacts on humans, structures surrounding transportation hubs, agriculture and the proliferation of ecosystems. Therefore, shifting to rail systems will minimize the impacts caused by thousands of trucks and will also generate substantial environmental and social benefits by reducing emissions, accidents and noise levels. For future work to recover from those impacts, the following points can be considered:

- Taxation can be a viable way to generate revenues that cover freight impacts. For example, in France and Switzerland, vehicles pay tax based on the vehicle’s travelled distance, weight and emission level in addition to the freight licence. There are no parallel examples of combined taxation and freight licence fees in the GCC area, so this may be a key consideration for future regulations and policy changes.

- Tolls can also be used as a charge to aid in recovering from impacts and can also simultaneously generate revenue to address externalities. Examples of the use of tolls are taking place in the U.K. and other European Union countries, where tolls have been introduced that cover external costs and some of costs associated with air pollution. Coverage of costs linked to noise and vibration will depend on the class of the vehicle. The Council of the European Union suggests that funds generated through tolls can also be used in making transport more sustainable as well as using these funds to support research and development into cleaner technologies. The UAE has begun applying some of these same principles to generate revenue, as well as to address congestion problems. More widespread use of tolls in other GCC countries could result in a more cohesive set of processes when opportunities for transport linkages are assessed.

- Implementing restrictions on the quantity of drivers’ working hours could be also a good regulation to aid in reducing accident rates and impact costs. Drivers may overload their trucks in scenarios where working hour regulations are not as stringent in order to deliver more shipments in a constrained time period, and the probability of accidents can increase when a truck weight exceeds maximum weights and when drivers are under pressure to over-deliver.

- Incentivizing shifts from truck to rail or to intermodal systems is key for shippers’ participation in reducing environmental and societal impacts. Encouraging shippers to change their mode selection can relieve congestion and lower accident rates.

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