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Urban Freight Regulations: How much they cost the consumers?

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Abstract

The paper discusses a multi-criteria decision-making model to identify costs due to time-windows based vehicle entry restrictions as percentage of product retail price. The study was done for two Indian supply chains in carbonated beverage, and fashion and clothing product categories from retailer's, supplier's and 3PL logistics player's perspective. Profit differential for scenarios when urban freight regulations were in place and when they were not in place were analysed for varied service levels of back orders and time-windows based entry restrictions. We found that for various decision-making and cost bearing structures, profit differentials varied from -6.0% to 7.5% of the product retail prices. The results highlight the comparative significance of urban freight regulations for the respective supply chains in developing country like India, and emphasise upon the need for changes in supply chain strategy to reduce costs due to urban freight regulations.

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1. Introduction

Urban freight movement is seen as one of the major contributors toward congestion and pollution within the urban areas (Crainic et al., 2009; Muñuzuri et al., 2018; Quak et al., 2016). This understanding has led towards freight movement based regulatory restrictions within the urban areas. Current research work is mostly focused towards studying the implication of modal shift of urban freight (Taniguchi et al., 2014) or feasibility of cleaner fuel operated fleet (Van Duin et al., 2013). Majority of research is confined to the developed world with limited data and information availability (Allen et al., 2012a; Kaszubowski et al., 2018; Mulholland et al., 2018). A study of European cities Bologna, Poznan, Budapest and Rijeka by Comi et al. (2018) to analyse variances in socio-economic and commercial pattern in logistics movement, for the first time collected data through survey for cities of 1 million or less population and found that the pattern and solutions varied for different urban area characteristics like urban form and street pattern etc. thereby, limiting the effectiveness of replicated measures. Developing and underdeveloped countries rising pollution levels mostly enforce traditional measures like time-windows based spatial segregation and restrict freight movement within city limits during intra-day time periods (Mulholland et al., 2018). Limited research is available to understand the cost impact of loss of service levels and performance of buyer, supplier and 3PL players associated with the supply chain due to these regulations (Anand et al., 2012; Comi et al., 2018; Gatta and Marcucci, 2014; van Duin et al., 2017). Therefore, this paper attempts to understand the cost of time-windows based urban freight regulations as percentage of product retail price considering multiple decision making and cost sharing models for supply chains functioning within urban area of India.

The paper is divided into six sections. First section introduces the problem. The second section provides gap identification through literature review. The third section discusses the model and subsequent variations. In the fourth section, supply chain characteristics of carbonated beverage, and fashion and clothing company have been discussed. The fifth section discusses analysis and findings. Conclusions are presented in the sixth section and seventh section discusses the model limitations and future research.

2. Literature Review

Research work focused towards reducing pollution and congestion have found that initiatives like goods consolidation and time-windows restrictions increase cost of urban freight movement. Russo and Comi (2016) state that policy measures to reduce congestion and emission positively affect residents but are resisted by logistics operators, fearing increase in transportation costs. 15 projects like introduction of low emission vehicles, goods consolidation and activity based time regulation, implemented in Paris as part of Integrated Urban Freight Model resulted in 59% emission reduction against 17% increase in cost (Patier and Browne, 2010). Model for 119 operators by Vidal Vieira and Fransoo (2015) found that time and zone restrictions based regulations result in detour and reduce logistical performance. Allen, Browne, & Cherrett (2012) found that implementing pollution reduction policies like suburbanisation of warehousing activities reduced vehicle kilometres travelled (VKT) and warehousing rent, but increased the per trip cost in 14 urban areas of the UK. Similarly, in Rome, an increase of 200 Euros for annual entry fees required 25% higher probability of finding a vacant parking bay and translated as provision for 820 additional parking bays (Filippi et al., 2010). Improvements done in Barcelona for better utilisation of urban consolidation centre (UCC) by 10 companies having highest market share found no significant benefits (Roca-Riu et al., 2016). Crainic et al. (2009) found that city distribution centres (CDCs) increase the cost of product movement.

However, conversely some studies have found significant reduction in vehicle operating cost. Study of 114 UCCs across 17 countries found a load factor improvement ranging between 15% to 100% and vehicle operating cost reduction (VOC) of nearly 60% (Allen et al., 2012b). Ando and Taniguchi (2006) found a reduction of 4% in operating cost and 46% in penalties through introduction of Travel Time Reliability in Vehicle Routing Problem for the city of Osaka, Japan. A study for the city of Zaragoza, Spain for Multiple Distribution Centres found reduction of 3% in travel time and 15% in urban distance travelled (Escuín et al., 2012). Recent research works have been focusing upon use of two-wheelers in moving urban freight (Taniguchi et al., 2014) and reducing fuel consumption, thereby calling it pollution routing problems (Soysal et al., 2015; Suzuki, 2016). Study of freight truck movement pattern data for Tokyo Metropolitan Area found that travel pattern depends upon truck sizes and weight assigned road network might increase freight movement within residential areas (Oka et al., 2018). Use of electric vehicles, with maximal operating range as a constraint found 36% to 90% CO_2 reduction and 19% VKT reduction for taxis

(Quak et al., 2016; Van Duin et al., 2013). Barring few studies e.g. study of marginal value of time from the perishable products perspective (Blackburn and Scudder, 2009) and identification of sources of uncertainty for supply chains in the Netherlands (Van der Vorst and Beulens, 2002), product specific research remains limited. Kumar et al. (2017) have studied the cost impact of urban freight regulations on carbonated beverage company and found it to be significant enough for change in supply chain strategy.

In addition, studies recognise the complex environment with multiple interacting stakeholders (Anand et al., 2012; Lindholm and Browne, 2013; Marcucci et al., 2015; Marcucci and Gatta, 2016). Gatta et al. (2017) state that urban freight management has high social cost. Their study identified various stakeholders involved and analysed data using multiple methodologies like Transport Network Analysis and Simulation, Behavioural and Business Model Analysis, Gamification and Key Performance Indicators. Research work by Le Pira et al. (2017a) analyse existing models that can be utilised for participatory decision support. They propose an agent based discrete choice model for stakeholder participation, accommodating heterogenous technical, economical and behavioural choices of stakeholders (Le Pira et al., 2017b). Marcucci et al. (2017) discuss an urban development model encompassing collaborative model for government and residents of Turin, Italy, resulting in increased vehicular speed, reduced CO_2 emission and improved deliveries. Bjerkan et al. (2014) study of stakeholder's perception about green supply chain measures found a positive response for night deliveries and lower preference for mobile depots, emphasising the need for achieving a common ground and ensuring better adoption. Marcucci et al. (2017b) provide a multi-layered agent based discrete choice model for simulating various policies for the city of Rome and ranking them for consensus building participatory process. Stakeholder based research work by Kin et al. (2017) using AHP found highest Eigen vector weightage for UCCs. Study of behaviour of Logistics Service Providers in UCCs of Netherlands using Q-methodology found unwillingness of private players for adoption of green logistics measures (van Duin et al., 2017). Quak et al. (2016) discuss the adoption of electric vehicles for urban freight activities and cite technical performance, reliability, high maintenance and lack of infrastructure as the main hurdles toward accelerated adoption. Muñuzuri et al. (2018) developed an emission and cost reducing vehicle routing problem for the city of Seville, Spain for four different product categories considering peak and off-peak delivery and waiting time at traffic lights. Sun et al. (2008) have developed a bi-level programming model for location of distribution centres.

However, very few researchers have analysed urban freight regulations from product retail price perspective in developing countries like India with different urban pattern and governance structure from developed countries. Most of the studies quantify per-trip or lifetime ownership cost variation and savings, and not product specific cost burden at the retail price level, thereby establishing the need for studies which can measure the cost of such regulations as part of product retail price and how much it costs the supply chain. Further sections in this paper discuss the model developed for identifying the cost heads for two supply chains in India, where time-windows based regulations are used to segregate the freight from passenger traffic and results in delayed product deliveries, forcing either buyer, supplier or the 3PL logistics player to pay the penalties to other stakeholders involved.

3. Model Development

3.1. Model Variations for Supply Chain Cost Bearing and Decision-Making Structure

The stakeholders directly involved from the cost perspective are government or the local administration; supplier/ seller/ manufacturer; retailer/ buyer and 3PL player/ freighter. Various costs would be paid and accepted by these stakeholders during the freight movement. Barring the government, the other three stakeholders will pay the taxes, toll charges and penalties to the government or each other as per the terms and conditions agreed upon. Based on the decision-making agent regarding order quantity and payment of tolls and penalties, varied models can be developed and most suitable model with the least cost can be proposed as against the existing model.

Since, bi-level programming has been traditionally used for multi-actor hierarchical decision making where actors attempt to optimise independently (Bektas et al., 2015; Colson et al., 2007), to study the cost effect of urban freight regulations on stakeholders e.g. supplier or retailer, use of bi-level programming is most suited. Table 1 shows all the possible model variations. Equations for Model 1 have been shown from equations (1) to (9), where, freight regulations influence the retailer who is the decision-maker and also bears all costs. Standard notations for the equations have been provided below and detailed notations along with values have been provided in annexures.

Notations

c	Production Cost	w	Wholesale Price
Q	Batch Size	α	Service Level
β	Restricted Time Entry Share	π_R	Profit Retailer
π_s	Profit Supplier	π_G	Positive Social Cost Benefit

Table 1: Model Variations Based on Decision Making and Cost Sharing

Model	Stakeholder within Supply Chain	Decision Making Stakeholder	Cost of Regulation Borne by	Remarks
Model 1	Retailer	✓	✓	
	Supplier			
Model 2	Retailer	✓	✓	Cost sharing and delay penalties paid by supplier to buyer
	Supplier		✓	
Model 3	Retailer	✓	✓	Cost sharing and no penalty paid between buyer and supplier
	Supplier		✓	
Model 4 (3PL)	Retailer	✓	✓	Same as Model 1 with introduction of 3PL
	Supplier			
Model 5	Retailer	✓		
	Supplier		✓	
Model 6	Retailer		✓	Cost sharing and delay penalties paid by supplier to buyer
	Supplier	✓	✓	
Model 7	Retailer		✓	Cost sharing and no penalty paid between buyer and supplier
	Supplier	✓	✓	
Model 8	Retailer		✓	
	Supplier	✓		
Model 9	Retailer / Supplier	✓	✓	Supply chain owned by a single player

Equation 1 is the upper level objective function optimising the retailer's profit as it is the decision-maker as well as the cost bearing agent and is sensitive to order quantity (*Q*), supplier's service level due to over-shipment or under-shipment *(α)* and service level due to urban freight regulations – i.e. penalties paid for moving the share of order quantity or quantity delayed *(β)*. Equation 2 is the lower level profit optimisation function for supplier. The upper level decision-maker (supplier in the Model 1) decides *Q* and *α,* while retailer in Equation 2 decides *β.* Equation 3 is the government's social cost constraint which needs to remain positive and includes earning due to toll, penalties and cost of negative externalities like pollution and congestion. Equation 4, 5 and 6 are wholesale price, retail price and production cost constraints respectively. Equation 7 is the production capacity constraint for manufacturer. Equation 8 is the minimum profit constraint and equation 9 is the non-negative constraint. Similar equations were developed by varying the objective and other constraint function for remaining models 2 to 9. Further detailing of equations 1, 2 and 3 have been shown in equation 10, 11 and 12.

$$Min. -\left(\pi_R\,(Q,\alpha,\beta)\right) \quad (1)$$

$$s.t.\; Q \in \begin{cases} Arg\ min. -\left(\pi_S\,(Q,\alpha,\beta)\right) & (2)\\ s.t.\pi_G \geq 0 & (3)\\ w_1 \leq w \leq w_2 & (4)\\ c_1 \leq c \leq c_2 & (5)\\ p_1 \leq p \leq p_2 & (6)\\ 0 \leq Q \leq Cap & (7)\\ Revenue\ (Q) - Cost(Q) \geq 0, k & (8)\\ 0 \leq \alpha,\beta \leq 1 & (9)\end{cases}$$

$$\pi_R = (p-w)\cdot D - \frac{(\alpha)Q}{2}\cdot h + h_s^- \cdot\ (1-\alpha)\cdot(1-\beta)Q \quad for\ D < Q \ldots\ldots\ldots(10a)$$

(Profit) + (Inventory-keeping cost) + (Over-shipment / Under-shipment penalty)

$$\pi_R = (p - w)Q \; for \; D > Q \; \dots\dots\dots (10b)$$

$$\pi_S = (w - c) \cdot Q - \frac{Q}{C_i} \cdot T - (1 - \alpha)\frac{\beta \cdot Q}{C_i} \cdot Pe - \frac{Q}{C_i} \cdot \frac{d}{m} \cdot P_f - h_s^- \cdot (1 - \alpha) \cdot (1 - \beta)Q \; for \; D < Q \; \dots\dots\dots (11a)$$

(Profit) – (Toll paid) – (Late entry penalty) – (Cost of fuel) - (Over-shipment/ Under-shipment penalty)

$$\pi_S = (w - c) \cdot Q - \frac{Q}{C_i} \cdot T - \frac{\beta \cdot Q}{C_i} \cdot Pe - \frac{Q}{C_i} \cdot \frac{d}{m} \cdot P_f \; \dots\dots\dots\dots\dots\dots (11b)$$

(Profit) – (Toll Paid) – (Penalty no-entry time) – (Cost of Fuel)

$$\pi_G = \frac{Q}{C_i} \cdot (T + \beta \cdot Pe) + \beta\frac{Q}{C_i} \cdot \frac{d}{m} \cdot APR \cdot VAPR + \beta\frac{Q}{C_i} \cdot EVC \; \dots\dots\dots\dots\dots (12)$$

(Revenue Collection) + (Benefit due to average pollution reduction) + (Benefits due to average congestion reduction)

Where, Average Rate of Pollution (APR) is taken as 2,640 gm CO_2 per litre of fuel (*Ecoscore.Be*, 2018). The economic value of CO_2 (VAPR) is taken as (\$55) Indian National Rupee (Rs.) 3,300 per tonne (van den Bergh and Botzen, 2013). The average value of congestion in Indian conditions is taken as Rs. 50/hr (Singh and Sarkar, 2009). Values were inflation adjusted for the model.

The third term in equation 10a adheres to the condition that the vehicle would move during the restricted time-window only when penalty is less than the loss due to non-delivery i.e.

$$\beta\frac{Q}{C_i}Pe < h_S^- \cdot \beta \cdot Q \cdot p \; \dots\dots\dots\dots\dots (13)$$

$$i.e. \frac{Pe}{C_i} < h_S^- \cdot p \; \dots\dots\dots\dots\dots\dots\dots\dots (14)$$

For single ownership of the supply chain from manufacturing to retail (Model 9) the model reduces to single level MCDM problem as shown in equation 15 to 24.

The retailers and suppliers profit function would be integrated to make one function and another function would be government's benefit function. Following would be the two functions,

$$\pi = (p - w) \cdot D - (1 - \alpha)\frac{Q}{2}h - \frac{Q}{C_i} \cdot T - (1 - \alpha)\beta \cdot Q \cdot Pe, if \; D < Q \; \dots\dots\dots (15)$$

$$\pi = (p - w)Q - \alpha(D - Q)h_s^- - \frac{Q}{C_i} \cdot T - (1 - \alpha) \cdot (D - Q) \cdot \beta \cdot Pe, if \; D > Q \; \dots\dots\dots (16)$$

$$\pi_G = \frac{D}{C_i} \cdot T + \alpha \cdot \beta \cdot (D - Q) \cdot Pe + (1 - \alpha)(1 - \beta) \cdot APR \cdot VAPR \cdot D + (1 - \alpha)(1 - \beta) \cdot D \cdot EVC \; \dots\dots\dots (17)$$

The equations for the model 9 are shown from equation 18 to equation 24,

$$Min. - \left(\pi_{Supply\ Chain}\,(Q, \alpha, \beta)\right) \dots\dots\dots (18)$$
$$s.t. \pi_G \geq 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (19)$$
$$p_1 \leq p \leq p_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (20)$$
$$w_1 \leq w \leq w_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (21)$$
$$0 \leq Q \leq Cap \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (22)$$
$$Revenue\ (Q) - Cost(Q) \geq 0, k \dots\dots\dots. (23)$$
$$0 \leq \alpha, \beta \leq 1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (24)$$

3.2. Determination of β

Since the demand considered here is deterministic in nature β cannot be considered stochastic in nature. Using the constraints for penalty, β can be represented in terms of *Pe, Q* and α in the following manner;

$$\beta = \frac{no. of\ trips\ made\ during\ the\ restricted\ hours}{total\ no. of\ trips\ made\ for\ the\ annual\ demand} \dots\dots\dots\dots\dots\dots (25)$$

If, all trips during the restricted time window are considered due to stock-out, then a trip would be made only when;

Cost of Stock-out at the buyers end ≥ Cost of Inventory Holding at the supplier's end + Stock-out Penalty

(Considering batch is being supplied upon each order)

Hence,

$$\alpha \cdot D_i \cdot h_B^- \geq \frac{Q}{C} \cdot Pe, where\ D_i\ is\ demand\ for\ period\ i \dots\dots\dots\dots\dots (26)$$

Therefore, for the total demand;

$$\alpha \cdot h_B^- \cdot \sum_{i=1}^{N} D_i \geq \frac{N \cdot Q}{C} \cdot Pe \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (27)$$

$$\alpha \cdot h_B^- \cdot D \geq N \cdot \frac{Q}{C} \cdot Pe \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (28)$$

The models were run for cases $D>Q$ and for $D<Q$. The theoretical solution for the model provided iso-curves between the wholesale price, retail price and quantity size. The mathematical solution was in line with the outcomes of model when applied upon the companies considered for the case studies. The model was run for cases when regulations were in place and when they were not in place i.e. when $\pi_G \geq 0$ was part of the model and when it was not part of the model. The difference between both the cases is shown as percentage of retail of price. This was termed as profit differential due to the said regulations.

4. Supply Chain Characteristics of Selected Products

Two consumer products were chosen, one was low involvement product i.e. carbonated beverage and the other was high involvement product i.e. fashion and clothing (Murphy and Enis, 1986). This was done to capture the variation and the model sensitivity.

Carbonated beverage being a high volume-low value product bottling plants are situated close to the urban areas. Bottling plant supplying to City of Bangalore was studied. Transportation of bottles required specifically designed vehicles, hence, 3PL was not introduced, other details have been provided in Table 2. Daily retailer's demand was fulfilled with information relayed one day in advance using personal digital assistant. 70% of the annual demand was considered to be concentrated in 122 days of summer. Prices were considered fixed in short-term, other details have been provided in Annexure B.

The clothing company follows two production cycles a year and products are stored in a central warehouse in Bangalore. Products are shipped every 15 days based on the demand. The company uses a 3PL provider and mixing of freight was allowed (Table 2). Volumetric weight system was being used through cartons that can either accommodate the intended volume or upto 21 kilograms of weight. The rates varied between Indian Rs. 8 to 26 per Kg. Further details have been provided in Table 2 and Annexure B.

Table 2: Supply Chain Characteristics of Companies Studied

Company	Supply Chain Characteristics	Contract type (Buyer-Supplier)	Lead Time - Freight movement	3PL	Rate Structure	Penalty Structure
Fashion & Clothing	Efficient	Not Applicable	15 days	Yes (mixing allowed)	Volumetric Weight System	Based on consignment value and delay duration
Carbonated Beverage	Responsive	Short-Term	One day	No	Not Applicable	No Penalty

5. Results and Discussion

For all models, alpha and beta were varied between 0.70 to 1.00 at an interval of 0.05, this was done to reduce the number of iterations, without compromising upon the sensitivity of results. Company specific results have been corroborated and compared in Table 3 and 4. Table 5 provides across company comparison. Low service levels without regulations resulted in negative profit differential, this was due to the reason that low service levels resulted in more penalties as compared to gains due to no regulation in place. Further, supplier profit was relatively more sensitive to beta as compared to the retailer, due to the fact that in most of the cases supplier pays the tolls and penalties. 3PL players were only being affected by the beta as should be the case.

5.1. Carbonated Beverage Company

Our analysis for two vehicle types of different capacities (C1 = 8,400 units and C2 = 5,760 units) found that use of large vehicle C1 is beneficial as both the vehicles come within the same commercial vehicle category as per the regulations. Table 3 provides the consolidated outcome for maximum and minimum profit differentials for the larger vehicle size C1. In all the cases, the least profitable scenario for retailers was 0.70 *(α)*, 1.00 *(β)* and most profitable was 1.00, 1.00. For supplier, the same was true for 0.70, 0.70 and 1.00, 1.00 respectively. We found that Model 5 as the existing setup (Table 3) has a low profit differential for retailer at 3.24% as well as for supplier at 2.33%. Model 4 (introduction of 3PL, Table 3) and 9 are more efficient models, where more profit differential could be achieved for both the players (Table 3). This means that the carbonated beverage company can further improve its profit margin by shifting to a 3PL player rather than owning its own fleet.

Table 3: Profit Differential across various Models – Carbonated Beverage Company

Model	Model Details	Retailer (%)		Supplier (%)		3PL (%)	
		Max.	Min.	Max.	Min.	Max.	Min.
1	Decision – Retailer Cost – Retailer	4.81	-4.11	0.00	0.00	NA	NA
2	Decision – Retailer Cost sharing and Penalty	4.25	-0.31	1.48	-2.73	NA	NA
3	Decision – Retailer Cost Sharing and No Penalty	4.15	-2.03	0.65	-0.87	NA	NA
4	Decision – Retailer Cost – Supplier	7.52	1.00	1.35	-2.73	0.83	0.83
5	Decision – Retailer Cost – Supplier	3.24	-0.91	2.33	-2.01	NA	NA
6	Decision – Supplier Cost – Supplier	3.24	-0.91	1.31	-2.25	NA	NA
7	Decision – Supplier Cost Sharing and Penalty	3.89	0.67	1.84	-2.37	NA	NA
8	Decision – Supplier Cost Sharing and No Penalty	3.89	-3.40	0.65	0.24	NA	NA
9	Decision – Supplier Cost – Retailer	7.52	1.00	1.35	-2.73	NA	NA

5.2. Clothing Company

Model 4 as the existing structure with a 15 days transportation lead-time is optimal one, however, if the supply chain shifts from an efficient to responsive policy of 7 days, the costs would be higher. A 7-day lead-time and no mixing of freight, resulted in heavy penalisation of 3PL provider and benefits in terms of negative profit differential for buyer or supplier (Table 4; next page). Most suitable model then would be 3b. However, the gain of 0.25% for retailer is not significant enough for a shift in the overall strategy. Use of 3PL with 7-day window and freight mixing also resulted towards profit differentials being zero for multiple models, meaning mixing of freight neutralises profit gains through penalisation.

6. Conclusion and Across Company Analysis

Most suitable model for both the supply chains has been detailed in Table 5. Based on the analysis carbonated beverage company needs to look into their strategy to reduce costs due to urban freight regulations. Costs for clothing company are not significant. However, if any of them shifts to responsive supply chain strategy, which in future might be the case for clothing company, the cost of urban freight regulations would increase significantly and might require strategic reconsideration.

Table 4: Profit Differential across various Models – Clothing Company

Model	Model Details	Retailer		Supplier		3PL	
		Max.	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
1	Decision – Retailer Cost – Retailer	0.00	-6.00	0.00	0.00	4.75	0.00
2	Decision – Retailer Cost and Penalty Sharing	0.00	-3.00	0.00	-3.00	6.00	0.00
3a	Decision – Retailer Cost Sharing and Penalty to Retailer Paid by 3PL	0.00	-6.00	0.00	0.00	6.00	0.00
3b	Decision – Retailer Cost Sharing but Penalty Paid to Supplier by 3PL	0.25	-0.17	0.00	-6.00	6.00	0.00
4	**Decision – Retailer** **Cost – Supplier**	**0.00**	**-0.24**	**0.00**	**-6.00**	**6.00**	**0.00**
5	Decision – Supplier Cost – Supplier	0.00	-0.13	0.00	-6.00	4.75	0.00
6	Decision – Supplier Cost and Penalty Sharing	0.00	-3.00	0.00	-3.00	6.00	0.00
7a	Decision – Supplier Cost Sharing and Penalty to Retailer Paid by 3PL	0.00	-1.87	0.00	0.00	1.80	0.00
7b	Decision – Supplier Cost Sharing but Penalty Paid to Supplier by 3PL	0.25	-0.17	0.00	-6.00	6.00	0.00
8	Decision – Supplier Cost – Retailer	-1.13	-7.13	1.13	1.13	6.63	-6.00

Our findings suggest that not all supply chains need a strategic change as marginal profit gains are not significant as in the case of clothing company (Table 5). However, change in nature of supply chain strategy might affect the clothing company as it is prone to rapid change in trends. A responsive supply chain might increase the cost multi-fold, in such a scenario the model can be used to understand the impact. We found that not all industries are affected in the same manner by such regulations and hence, facilitation measures might not be adopted by all supply chains in the manner intended by local administration. This might affect the overall adoption and success of regulations forcing reconsideration. On the other hand, the model could be utilised to facilitate or restrict specific companies or sectors.

Table 5: Cost of Urban Freight Regulations – Across Company Analysis

Company		Beverage	Clothing
Most Suitable Models		Model 4 or 9	Model 3b or 7b
Maximum Differential (Retailer / Buyer)		6.06	0.25
Minimum Differential (Retailer / Buyer)		2.78	-0.17
Maximum Differential (Supplier)		1.35	0.00
Minimum Differential (Supplier)		-2.73	-6.00
Maximum Differential (3PL)		0.83	NA
Minimum Differential (3PL)		0.83	NA
Strategy Change	Retailer / Buyer	Yes	No
	Supplier	Yes	Yes
	3PL	Needs to be introduced	NA

7. **Implications and Future Research**

The research work provides a model to identify costs limited to urban freight regulations for entry restriction, however, the length of the restriction period and its sensitivity can be further studied. The model could be adapted to study implications of other regulations affecting the supply chains. The study discussed just two companies, hence, future research can be taken up to study the implication of urban freight regulations on various other supply chains of similar or different product categories. The model could be modified to introduce government as the third decision maker, thereby making it a tri-level programming model.

Appendix A. Supply Chain Characteristics of Selected Industries

Table A.1: Delay Penalties – Clothing Company

No. of days delay	Penalty applicable
1 day	Grace Allowed
2 Days	2% of Freight Value
3 Days	4% of Freight Value
4 Days	6% of Freight Value
5 Days	8% of Freight Value
More than 5 Days	10% of Freight Value

Appendix B. Product Costs for Industries Studied

Table B.1: Various Parameters and Variables- Clothing Company

Clothing Company		
Item	**Unit**	**Value**
Average Demand (*D*)	SKU/15 Day Cycle	3,250
Average Price (*p*)	Rs. / SKU Unit	4,000
Toll Paid (*C1*)	Rs. / Truck	800
Average Package Capacity	SKUs / Carton	12
Capacity (*C1*)	Cartons / Truck	500
Capacity (*C1*)	No. of SKUs	6,000
Rate / Carton	Rs.	26
Urban Area Dist. (*d*)	Kms.	10
Total Travelled Dist. (*x*)	Kms.	1,418

Table B.2: Values of Various Parameters and Variables- Carbonated Beverage Company

Decision Maker	Item	Value
Supplier	Production Cost (*c*)	Rs. 3
	Wholesale Price (*w*)	Rs. 8
	Demand (*D*)	271,786 Units
Retailer	Retail Price (*p*)	Rs. 10
	Inventory Keeping Cost (*h*)	0.10 of Retail Price
	Back Order Penalty (h_s^-)	0.15 of Retail Price
Fixed	Vehicle Capacity (*C1*)	8,400 units
	Vehicle Capacity (*C2*)	5,760 units
	Urban Area Distance (*d*)	25 Kms.
	Mileage (*m- C1*)	2.5 Kmph
	Mileage (*m-C2*)	3.0 Kmph
Government	Toll for Urban Area Entry (*T*)	Rs. 400
	Penalty (*Pe*)	Rs. 2,000
	Price of Fuel (p_f)	Rs. 60 / litre
	Average Pollution Reduction (*APR*)	2,640 gms. CO_2/Litre
	Value of Average Pollution Reduction (*VAPR*)	Rs. 3,300/Tonne
	Economic Value of Congestion (*EVC*)	Rs. 50/hour

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