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Analysing Truck-Trailer-Flatrack Mix for a Given Road Network with Known Supply and Demand

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Abstract: A flatrack is a modular, flat transport structure that can be seen as a larger version of a pallet. As compared to a pallet, a flatrack can accommodate a higher load volume and weight for transportation or storage, under specific supply and safety conditions. Their structure is durable, hence they can be reused many times like shipping containers. A loaded or empty flatrack must be carried by a truck or trailer for transportation from one location to another. The flatracks can be loaded onto a vehicle and unloaded from a vehicle together with its cargo via a mechanical arm integral to the vehicle. As such they act as a module to the trucks and trailers and facilitate rapid loading and unloading of cargo.

We consider an organisation that intends to include flatracks in their vehicle fleet of trucks and trailers for transportation of cargo, from their own sources to destination locations, through specified road networks within given time windows. The loaded flatracks are unloaded (from the trucks and/or trailers) at their destinations as a single unit with their cargo, and as such they are not free for reuse until they have been emptied of cargo. This means that the flatracks may remain at the destination location for some time, and then the empty flatracks can be collected and returned to the source location for further use. A truck and trailer can carry multiple empty flatracks. Any delay in cargo removal from a flatrack and in empty flatrack collection may require the use of more flatracks in the system. On the other hand, frequent flatrack collection with partial vehicle loads might require more convoys to be operated. So a compromise between these two strategies is likely needed.

The purpose of this research is to determine the number of flatracks required as part of a fleet composed of a given number of trucks and trailers, such that the fleet can adequately perform a set of predefined tasks. We have undertaken a simulation based study to analyse the performance of the system with three different flatrack recovery policies. Here, we assume there are adequate supplies at the supply nodes and the demands at the demand nodes are known in advance with their required time windows. Further the road network is fixed and given. With limited representative data, the simulation results show interesting insights that are useful for decision making.

Keywords: *Simulation, flatrack, logistics, vehicle fleet mix, fleet management*

1 INTRODUCTION

Flatracks act as a module to trucks and trailers that can be loaded onto a vehicle and unloaded from a vehicle together with its cargo via a mechanical arm integral to the vehicle. Hence, they provide the convenience of preparing and delivering cargo without the presence of a truck or trailer, other than for its actual transportation. Organisations can improve the efficiencies of their logistic operations by utilising flatracks in their vehicle fleet mix, as they significantly reduce the truck and driver waiting time. However, such efficiencies depend on how the flatracks are managed and recovered in the system. For example, if the flatracks are not collected promptly, the system will require more flatracks (increased capital costs) whereas if the flatracks collection is too frequent that will result in increased operational costs such as fuel costs.

In this paper, we consider an organisation that intends to include flatracks in their vehicle fleet comprising trucks and trailers. The organisation needs to assess the number of flatracks required in their logistic system in order to carry out predefined sustainment operations using their own transport assets. Given that the number of flatracks required in the system depends on how flatracks are managed and recovered, it is important to carefully consider various flatrack recovery policies in order to evaluate associated capital and operational costs. In this work we present a simulation based study to measure the performance of logistic operations of the organisation under three different flatrack recovery policies. The simulation was applied to determine the number of flatracks required under the three recovery policies when the number of trucks and trailers in the system are given and to determine the impact of different flatrack recovery policy on the average truck turnaround time. The organisation has a fixed network structure with different road conditions and restrictions on night time driving. It is assumed that adequate supply is available at the supply nodes and the transport tasks are known in advance within the required time frames.

The three examined flatrack recovery policies chiefly vary by the frequency of flatrack collection and the truck/driver waiting time. The first flatrack recovery policy has the most infrequent flatrack collection where the flatracks are recovered on the subsequent day. Trucks coming from the parent nodes leave the flatracks at the destination nodes without waiting until the cargo is unloaded. The next examined recovery policy allows the trucks to recover the flatracks in the same journey by waiting at the destination nodes until the cargo is unloaded from them. According to the third policy, the flatracks are recovered on the same day by the parent nodes by sending additional convoys with partial loads. Trucks do not wait at the destination nodes until the cargo is unloaded. The experimental results show different tradeoffs associated with each recovery policy (in particular the total number of flatracks required and average turnaround time) which can be used to further analyse the costs and benefits of each flatrack recovery policy considering both capital and operational costs.

2 RELATED WORK

Incorporating vehicle modules such as flatracks in the vehicle fleet mix in a military setting has been studied as a modularised fleet mix problem in Baker et al. (2007) and Abbass et al. (2006). However, to the best of our knowledge none of the work found in the literature have studied the recovery policies of flatracks or their impact on the operational efficiencies on the supply chain.

Transportation of sugarcane via road networks has similar properties to the distribution of cargo via flatracks. A typical sugarcane transportation system consists of the following steps: arrival of the empty truck to the field; loading the truck and fastening the loaded trailer to the truck; travel of the loaded truck to the factory; weighing the truck and the trailer; unfastening the trailer to be unloaded; unloading the truck; weighing to obtain the net weight of sugarcane; attach an empty trailer (optional) and travel back to the field. In a sugarcane transportation system, a low lead time (the waiting time from the start time of cutting sugarcane to the time of grinding at the mill) is highly desirable as any delays (including loading and unloading delays) in delivering the sugarcane directly affect the quality of the sugar produced by the mill (de Assis Rangel et al., 2010). Therefore, loading and unloading times of sugarcane, waiting times in queues and recovery strategies for trailers are important parameters for the efficiency of such a system.

A number of works in the literature employ simulation and simulation optimisation techniques (Andradóttir, 1998) to identify various bottlenecks, relations between the processes and evaluate different alternatives in order to optimise sugarcane transportation systems. Iannoni and Morabito (2006) apply a discrete event simulation to analyse alternative configurations and policies to optimise the truck waiting time in the reception area in sugar mills. Two key performance measures were considered i.e: the mean unloading rate of sugarcane and the mean amount of sugarcane waiting in queues. The results of the study show that by releasing trailers in an intermediate storage significant improvements can be achieved in terms of the above mentioned performance measures. de Assis Rangel et al. (2010) present a simulation model to analyse the variation of the profit considering the variations of three factors: travel time, unloading time and number of trucks. A 2^k factorial strategy was applied by varying a factor (k) between two levels at a time while keeping other factors fixed. As such, 8 (2^3) scenarios were analysed to understand the fluctuation of profit as a function of the above mentioned three factors. Díaz and Perez (2000) employ Simulation and Response Surface Methodology in order to support the decision making process for a sugar cane transportation system in allocating resources on a daily basis. The number of allocated resources, and the average truck speed were identified as the controllable parameters whereas the total quantity of cane transported and average travelling time were identified as the output variables.

The process of empty shipping container repositioning also exhibits similar properties to the process of empty flatrack management. Shintani et al. (2007) highlight the importance of empty container repositioning in the sea container industry in order to meet cargo demand in a timely manner. A discussion on challenges in managing empty container repositioning can be found in Braekers et al. (2011). Dang et al. (2012) study empty container repositioning policies in a port area with multiple ports. Three policies, namely positioning from overseas ports, positioning from inland, and leasing are studied in order to optimise the total cost based through simulation and optimisation techniques. A simulation optimisation tool was developed by Dong and Song (2009) to optimise container fleet size and empty container repositioning policy with the objective of minimising the expected total cost. The expected total cost consisted of inventory holding cost, lost-sale penalty costs, lifting-on costs, lifting-off costs and laden/empty container transportation costs. The system was formulated as an event-driven system with the events being vessel arrivals and departures. The performance of the system was evaluated via the simulation model with the control parameters being fleet sizing and repositioning rules. An evolutionary optimisation algorithm was employed to explore the optimal values for control parameters and the results obtained through case studies showed that the simulation optimisation approach serves as a useful tool to determine the container fleet size and empty container reposition rules.

3 CASE STUDY

In this case study we consider an organisation which intends to use flatracks in their vehicle fleet of trucks and trailers for transportation of goods from their own sources to their demand nodes, through specified road networks within given time windows. The network structure is shown in Figure 1. Node 1 acts as the parent unit (strategic unit) of the supply chain. It forwards stock for sustainment operations daily to the warehouse shown as Node 2. The warehouse re-configures the stock coming from Node 1 and forwards it to its serving units shown as Node 3, Node 4 and Node 5. Node 3 is geographically isolated from the other nodes, therefore it has its own transport assets for sustainment operations. In other words, the trucks from Node 3 come to Node 2 to collect its stock daily.

Distances between the nodes and their road conditions are marked on the edges in Fig. 1. For a good road the day time mean speed is $40km/h$ and the night time speed is $20km/h$. For a bad road the day time speed is $35km/h$ and the night time speed is $17km/h$ whereas in hilly roads they are $30km/h$ and $15km/h$ respectively. In hilly roads trailers are not permitted. The convoys starting from Node 1 can only travel between daylight hours, i.e. they should leave the start point no earlier than 6am and be inside a secure location by 7pm. The convoys between Node 2 and Node 4 or Node 5 can travel day or night, however, convoys travelling to/from Node 3 should only travel between daylight hours.

The organisation wishes to investigate various tradeoffs between three alternative flatrack recovery policies. Due to geographic reasons and restrictions on night time driving the convoys coming from Node 1 and Node 3 cannot wait at Node 2 until the cargo is unloaded from flatracks or send additional convoys to Node 2 within a 24 hour period (The initial experiments indicated that if the trucks wait until the pallets are unloaded from flatracks (in order to return with the same flatracks), the convoys have to wait at Node 2 until the next day due to restrictions on night time driving. This mean that these nodes will require additional trucks to satisfy the next day demand.). Therefore, across the three flatrack recovery polices how Node 1 and Node 3 recover flatracks from Node 2 are kept fixed as follows. The convoys from Node 1 leave the flatracks together with cargo at Node 2 and return with any empty flatracks available for re-use. The convoys from Node 3 carry empty flatracks, leave them at Node 2 and pick up loaded flatracks configured as per the material requirements of Node 3. Between these nodes (Node 1 and Node 2, and Node 3 and Node 2) no re-supply will be conducted within a 24 hour time frame (Therefore any flatrack left at the destination nodes can only be recovered on the next day). For other nodes the investigated three flatrack recovery policies are described below.

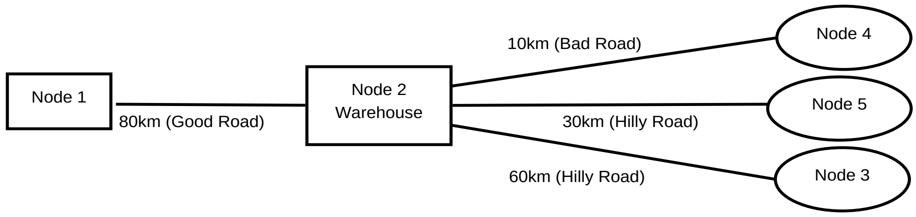

Figure 1. Typical network structure of the case study: The diagram illustrates the supply and distribution nodes. Node 1 forwards the supply to Node 2 which acts as a warehouse. Other elements receive their supply from Node 2. Node 3 receives its supply from Node 2 however, using its own trucks. Distances between the nodes and their road conditions are marked on the edges.

Flatrack recovery policy 1. According to flatrack recovery policy 1, the flatracks are primarily recovered on the subsequent day. Therefore there is no wait at the child nodes. At Node 4 and Node 5, the convoys (coming from Node 2) leave the flatracks together with cargo and return with any empty flatracks available for re-use. No re-supply will be conducted for any node within a 24 hour time frame (Therefore any flatrack left in the other nodes can only be recovered on the next day).

Flatrack recovery policy 2. According to flatrack recovery policy 2, the trucks wait at the child nodes to recover the flatracks. That means, at Node 4 and Node 5, convoys (coming from Node 2) wait till the pallets are unloaded from flatracks and return with the same flatracks.

Flatrack recovery policy 3. According to flatrack recovery policy 3, the trucks can recover the flatracks on the same day by sending an additional convoy with partial loads (i.e. without waiting at the leaf node until the cargo is unloaded) if there are adequate transport assets. In particular, at Node 4 and Node 5, convoys (coming from Node 2) leave the flatracks together with cargo and return with any empty flatracks available for re-use. Re-supply can be conducted to Node 4 and Node 5, if transport assets are available. Therefore, the daily supply can be sent in multiple convoys and the flatracks are collected during the re-supplies.

4 SIMULATION SYSTEM

A discrete event simulation has been developed to estimate the number of flatracks required by Nodes 1–3 under the three flatrack recovery policies for the above described case study. This system can be applied to address similar types of problems by varying the inputs. Although the system is deterministic at this stage it can easily be extended to address uncertainty in various aspects.

4.1 System Constants

Network structure. The network structure is shown in Fig. 1. Each Node has a set of incoming and outgoing edges and each edge has a number of properties such as the day and night speeds and road condition (e:g: good, bad, hilly).

Convoy Requirements. When travelling between nodes, a section of at least five vehicles must travel together.

Travel Restrictions. The restrictions on night time driving will apply as described in section 3. The default start time for a task is 6 am (i.e. start loading etc.) and upon completing a task the vehicles are required to return to the origin adhering to the constraints regarding night time driving specified in the case study.

Ownership Structure. The ownership structure keeps track of which node is in charge of which node. For example, Node 1 (as a parent) is responsible of delivering material to Node 2 (a child) and Node 2 (as a parent) is in charge of delivering material to its child nodes (Nodes 4–5). Node 3 collects its cargo from Node 2 using its own transport assets. The ownership structure also keeps track of the number of trucks, trailers and flatracks owned by each unit. Node 1 has 19 trucks and 19 trailers and Node 2 owns 11 trucks and 11 trailers. Node 3 has 7 trucks, but no trailers. Flatracks can be used by the other units, however, vehicles or trailers owned by a particular unit cannot be used by any other unit. A Truck and a trailer can carry 1 loaded flatrack each. A flatrack can be loaded with 8 pallets. A truck and trailer pair can carry up to 6 empty flatracks (3 each).

Table 1. Number of pallets from each category required by each node per day

	Cargo Type							
Destination	C1	C2	C3	C4	C5	C6	C7	C8
Node 2	32	6	10	29	6	9	4	15
Node 3	15	4	12	17	3	4	2	8
Node 4	15	4	11	8	3	3	2	7
Node 5	15	2	13	6	3	5	2	7

Material Requirement. The demand for sustainment operations are assumed to be known in advance and fixed for the time frame in consideration. The quantities of pallets required to be delivered to each node per day are given in Table 1. Category 1 (C1) and Category 7 (C7) can't be mixed with Category 3 (C3) or Category 4 (C4), therefore they are not allowed to load on the same truck or trailer. A vehicle and a trailer can carry 16 pallets (8 on each). Nodes 3–5 require water and fuel to be delivered on a daily basis, however they can only be carried in specialist vehicles which cannot carry flatracks. This means that in addition to the trucks required to deliver material given in Table 1, 3 specialist vehicles are needed to be sent to Nodes 3–5 on a daily basis. These vehicles can be used to satisfy the convoy requirements as required. The system allows specifying a required by time to prioritise deliveries/pickups, however, the objective is to deliver the materials as quickly as possible in order to avoid the risks of not meeting the demands.

4.2 Modelling Assumptions

In this simulation model a constant speed between the nodes (as described in section 3) was assumed. Further, the loading and unloading times were also assumed to be constant. At Node 1, the loading time is 2 hours (loading and unloading times are assumed to be the same for a truck with a trailer and a truck without a trailer) which includes loading, fueling and moving to the start point. 1 hour should be allowed at Node 1 for unloading tasks. At Nodes 2-5 flatrack loading/unloading time is 30 minutes during daylight hours and 45 minutes during the night. If the vehicles return with the same flatracks, pallets should be unloaded and this process takes 2 hours. Further, no vehicle breakdown or attrition was considered in the simulation.

4.3 Simulation Algorithm

We started the simulation with the given number of trucks and trailers. We also provided one flatrack per truck and one flatrack per trailer to start with. This approach was taken to avoid running the simulation for apparent infeasible fleet configurations. The simulation was run for a period of 7 days by inputting the initially estimated vehicle fleet mix. The time period for the simulation running period was chosen to understand the pattern of unmet demand and service delays while not requiring a significant computational running time. After completing 7 days, if there was any unmet demand or service delay, 1 flatrack was added to the relevant unit in the system and the simulation was re-run. The simulation was stopped when there were no unmet demand and no service delays within 7 consecutive days. The simulation algorithm is given in Algorithm 1. The event generation at this stage is deterministic as the material requirements are known in advance. If the required number of flatracks are not available in the supply node, the event is queued until the required number of flatracks arrives from some other node (if there are pending arrivals), however, this can cause service delays. If there are no pending arrivals and if the demand cannot be satisfied with the available number of flatracks it is considered as unmet demand.

4.4 Model Parameters and Performance Metrics

The initial distribution of flatracks at each node and the flatrack recovery policy are the model parameters that were varied in this simulation. The key performance metrics that were analysed using the above described simulation system were: the total number of flatracks required and the average truck turnaround time for each flatrack recovery policy.

5 SIMULATION RESULTS AND DISCUSSION

The required number of flatracks for each node, the percentage increase above the minimum number of flatracks required and the average truck turnaround time estimated by running the simulation considering each

Algorithm 1 Algorithm: Simulation Algorithm

```
while demand is not met within given time frame do
    generate events for 7 days
    add 1 flatrack to the system
    while event list is not empty do
        go to the first event in the queue
        advance simulation time to the time of event
        process event
    end while
end while
```

of the three flatrack recovery policies are shown in Table 2. The total number of flatracks required according to flatrack recovery policy 1 is 98, whereas the total number required according to flatrack recovery policy 2 is 92. The percentage increase above the minimum number of flatracks required (1 per truck and 1 per trailer) for these two policies are 47% and 37% respectively. Only 74 flatracks are required in total as per flatrack policy 3. This is only a 11% increase above the minimum. Clearly, when the frequency of flatrack collection is lower, more flatracks are required by the system. The average truck turnaround time (i.e. from the moment the trucks are loaded with cargo to the moment the trucks are free for another use) according to flatrack recovery policies 1, 2 and 3 are 9.65 hours, 10.06 hours and 8.61 hours respectively. Figure 2 shows the truck turnaround time as a function of number of flatracks used in the system. A slight increase in the average truck turnaround time can be observed when the total number of flatracks in the system changes from 98 to 92 (i.e. when the flatrack recovery policy changes from policy 1 to policy 2), whereas a significant decrease in the truck turnaround time is observed when the total number of flatracks in the system changes from 92 to 74 (i.e. when the flatrack recovery policy changes from policy 2 to policy 3). The truck waiting times at Node 4 and Node 5 are reflected in the increase in the average truck turnaround time for flatrack recovery policy 2. The average truck turnaround time as per flatrack recovery policy 3 is the shortest (despite the lowest number of flatracks required in the system compared to the other 2 policies) because of the reduction in truck waiting time as well as the availability of flatracks due to frequent collection. However, the simulation results show that for policy 3, 3 trucks are required to be operated a second time per day, an additional cost when compared to the other two flatrack recovery policies. There is also an additional $60km$ increase in the total distance travelled by the trucks per day for this policy. This is about a 12% increase in total distance travelled between Nodes 2, 4 and 5. This needs to be further assessed against the cost of buying additional flatracks (capital cost) and the associated operational costs such as fuel.

6 CONCLUSIONS AND FUTURE WORK

We have presented a simulation based approach to determine the number of flatracks required as a part of a vehicle fleet mix for a logistic system to carry out a set of predefined deliveries. We have analysed the average truck turnaround time of the system under three flatrack recovery policies. According to the simulation results,

Table 2. Estimated number of flatracks, the % increase above the minimum number of flatracks required (1 per truck and 1 per trailer = 67) and average truck turnaround time for each recovery policy

Policy	Node	No. of Flatracks	Total	% Increase above the Min	Turnaround Time (hrs)
1	Node 1	66			
	Node 2	25			
	Node 3	7	**98**	**47%**	**9.65**
2	Node 1	62			
	Node 2	23			
	Node 3	7	**92**	**37%**	**10.06**
3	Node 1	50			
	Node 2	17			
	Node 3	7	***74***	***11%***	***8.61***

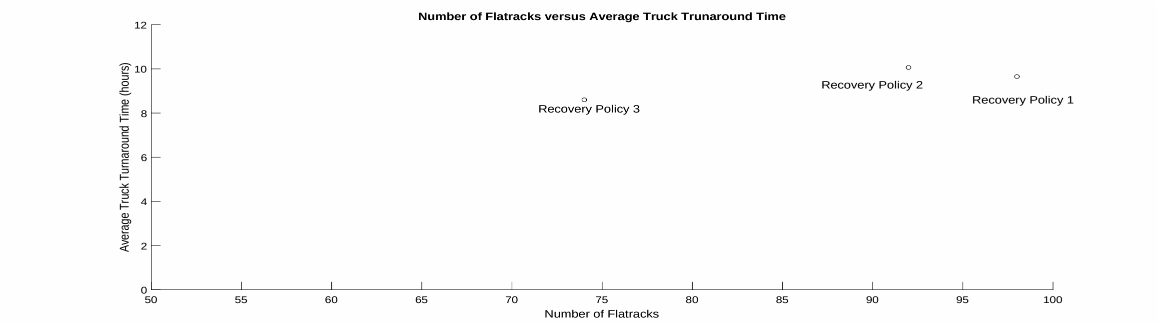

Figure 2. The number of flatracks in the system versus average truck turnaround time for three flatrack recovery policies

the flatrack recovery policy which recovers flatracks on the same day by sending additional convoys with partial loads (flatrack recovery policy 3) needs the least number of flatracks compared to the other policies which either wait to recover the flatrack on the same journey or recover the flatrack on the subsequent day. Moreover, this policy has the shortest truck turnaround time, however at the expense of additional operational costs in the form of additional convoys.

In future work we consider alternate network configurations, for example by establishing flatrack exchange nodes between the nodes that are widely geographically separated. This will enable the convoys to dump or cross-load flatracks at intermediary locations without needing to travel long distances. This is particularly useful to reduce driver fatigue. Further, the future work will be expanded to incorporate uncertainties and variability associated with daily demands and vehicle and flatrack attrition rates.

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