Platform for Logistic and Transport Utilizing Dynamic Transshipment Points

Markus Duchon and Claudia Linnhoff-Popien

Abstract—**Transportation and logistics are important factors for economic growth and prosperity. By providing services for cooperation in the distribution domain, which can be dynamically accessed and applied, the existing resources can be used more efficiently. Additionally, due to cooperation a better utilization could leverage the overall performance of long distance distribution services. In this paper we present a cooperative approach used within a logistic platform utilizing dynamic transshipment points. By this, freight can be exchanged on demand even if vehicles are on the move in order to save costs in terms of covered distances, better vehicle utilization, travel times, and so on. For information exchange, required for cooperation, common smart phones can be applied as they allow for location determination as well as communication capabilities at low investment costs. The feasibility and usefulness of the approach is demonstrated by simulation and the results presented indicate a high potential of savings.**

Index Terms—**Distribution platform, logistic and transportation, logistic service.**

I. Introduction

The transportation of freight is an important factor for economic growth and prosperity. But, especially in many emerging and developing counties it is a key bottleneck to global integration and is a serious drawback to the commercial exploitation of mineral resources or agricultural products. Reasons for this, among others, are the bad condition of the infrastructure itself, speaking of a bad state of the roads, a few number of vehicles and poor communication capabilities to support cooperation. Furthermore, many developing countries (not only) in Africa heavily depend on agricultural exports. One example is Tanzania, and according to the diagnostic trade integration study [1], the majority of international transport is by ocean freight and carried out by the major ports of Dar es Salaam, Tanga, Mtwara, and Mwanza (to Uganda). Nevertheless, the cargo must be either collected at, or distributed from these international transshipment points, which is mostly done by road transport. In 2003 nearly 50% of Tanzanias exports (882.000 tons) arrived in Dar es Salaam by road and about 80% of the imports leave the same harbour by road. Additionally to the poor infrastructure the "*transport costs faced by African countries are almost twice as high as the world average*" [2]. Hine et. al [3] compared the freight transport in Tanzania and Indonesia and the tonne kilometre for road transport in Tanzania was 0.087 US Dollar (at mid 1995 price) for trucks carrying 3 to 13 tonnes and 0.096 US Dollar over 13 tonnes. In their work several reasons are outlined which are also summarized by Poulton et. al [4]: Vehicle and fuel prices, truck utilization, and a higher journey speed (leading to higher fuel costs and increasing costs due to accidents). With our cooperative approach presented in this paper we want to face some of these issues within the transportation domain. Generally speaking, the goal is to utilize the available resources more efficient in order to reduce the overall costs associated with transport. Therefore, a platform is proposed which provides a service to enable cooperative transportation.

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Markus Duchon is with Siemens Corporate Technology, CT T DE IT 1, Otto-Hahn-Ring 6, 80200 Munich, Germany (e-mail: markus.duchon@ifi.lmu.de).

Claudia Linnhoff-Popien is with Ludwig-Maximilian-University Munich, Oettingenstr, 67, 80538 Munich, Germany.

Surveyed related work is broached in Section 2. Section 3 gives an overview of the platform for logistic and transportation including the requirements, which need to be considered as well as the proposed system design to enable transport utilizing dynamic transshipment points. Thereby, the communication, the matching process, as well as the main aspects of the simulation environment will be explained. The evaluation follows in Section 4 before a conclusion and an outlook on future work is given in Section 5.

II. Related Work

In the area of optimizing logistic processes a lot of work has been published in the last decades [5]-[9]. The travelling salesman problem (TSP) described by Bellmore in [10] can be seen as a super class for several problem specific manifestations, like the vehicle routing problem (VRP) and its derivatives using single (SVRP) or multiple (MVRP) vehicles and different restrictions like time windows (VRPTW), capacity (CVRP). Another subclass is pickup and delivery problems (PDP) where also different facets are considered. Furthermore, there exist problem cases which are static or dynamic as described by Berbeglia et al. [11],[12]. The main difference is that in the static variant the orders are known in advance whereas utilizing the dynamic case orders can be added during run time. There also exist several logistic platform approaches for freight distribution which unfortunately will not be discussed due to space constraints.

III. Platform for Logistic and Transportation

In this section the platform providing a logistic service utilizing dynamic transshipment points (TPs) is introduced and the main requirements the system needs to fulfil are discussed. Afterwards, the proposed design including the communication and matching process for freight distribution will be explained in detail. An overview of the system is illustrated in Fig. 1. Image two trucks are already on the move and departed from two different cities with combinable freight, the same destination and one of them with enough space to fit the other ones load. The according information is periodically sent to the platform which is required for matching the orders according to their parameters. Thereby, the estimated travel time is used to select a TP which can be reached by both trucks within a certain time interval and detours as small as possible. Concerning large distance transportation there need to be plenty of these TPs which can be chosen according to the vehicles' current locations. Whenever a match occurs a confirmation is transferred to both candidates including a suitable but dynamically selected TP. After the freight has been transferred, only one truck continuous to the destination and the other one can accept further transport orders or drive back home.

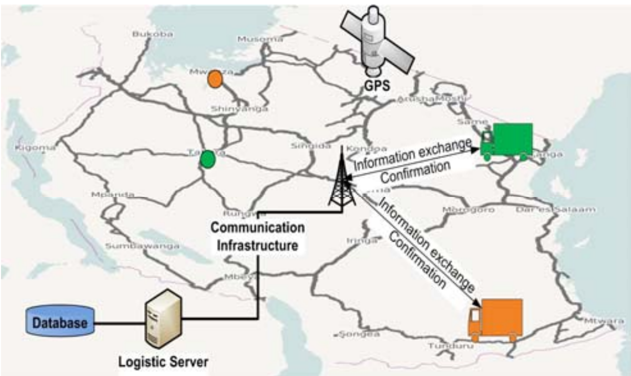

Fig. 1. System Overview

A. Requirements

In order to provide a system as described, some requirements (Tab. 1) must be fulfilled which will be explained in the following. To enable cooperation among trucks or their companies an appropriate communication infrastructure and client hardware including positioning capabilities are required. The logistic server is responsible to find appropriate candidates which are able to transfer their freight at a dynamically chosen TP. Therefore, an algorithm which considers the parameters mentioned before needs to be developed and evaluated. To handle requests from all over Tanzania the server as well as the matching algorithm need to be scalable and must provide a high availability. To evaluate the cooperative transport approach a simulation environment will be used to obtain as realistic results as possible. As basis a road network is essential, which can be used for certain measurements, like e.g. the freights' or trucks' covered distances and times. Thereby, speed restrictions should correlate with the observations made in [3],[4]. Also cities should be included which can be used as origins or destinations. Alongside the road network also TPs are required for the cooperative approach. Concerning these aspects also the large distance transport model of Tanzania regarding exports, imports and national transports should kept in mind. Furthermore, it would be beneficial to consider time windows for delivery and different classes of freight that require special treatment, like e.g. cooling, dry cargo, liquid substances. Besides the road network, the demand model, and different cargo, also trucks which actually carry out the transportation task are. Moreover, drivers need to be modelled which can only work for a certain amount of time until they need to rest.

TABLE I:. REQUIREMENTS FOR LOGISTICS AND TRANSPORT UTILIZING DYNAMIC TRANSFER HUBS

Infrastructure Components		
IC 1	Communication Network	Enables communication with the logistic server using e.g. cellular technologies
IC 2	On-board Units	Used in trucks to determine the position and enable communication
Logistic Server and Distribution Algorithm		
LD 1	Matching Process	An algorithm for freight consolidation considering certain parameters
LD 2	Scalability	To handle an appropriate number of requests
LD 3	Availability	To ensure a continuous logistic service
Simulation Environment		
SE 1	Road Network	Simulation basis for realistic vehicle movement and measurements
SE 2	Cities and Transshipment Points	Cities used as origin and destination for freight and transhipment points to exchange it
SE 3	Order and Demand Model	Freight which needs to be transported from an origin to a destination according to a demand model, including parameters (size, type, etc.)
SE 4	Trucks	Vehicles are responsible for the transportation task under certain restrictions (capacity, type, speed, etc.) and must be capable of routing and navigation
SE 5	Drivers	People driving the vehicles, but only for a certain amount of time until a pause is required

B. System Design

Ongoing we will present the proposed system, based on client-server architecture, following the requirements (IC 1 and 2). The client represented by an on-board unit can be either integrated into the trucks using embedded devices (car PC) including a GPS receiver and a cellular communication unit or loosely coupled using a common smart phone with an integrated GPS receiver and GPRS/UMTS capabilities. According to mobileworldlive[1] the GSM coverage seems to be sufficient along the major roads and in the bigger cities. In either case the client's device must determine the current location and has to store additional information about the truck, the driver's status, and the freight which will be explained later on. This information will be transmitted to the logistic server periodically. The server can also work in a distributed manner whereby each one is responsible for a certain type of freight or for a certain area to reduce the load and enable scalability (LD 2). But as for now, we will concentrate on a single instance for explanation purpose. A

[1] http://www.mobileworldlive.com, 23. January 2012

database is attached to the server which main purposes are to store the incoming information from the clients and provide geoinformation about the road network (including cities and transhipments points). The latter is also necessary for the matching process in order to estimate the reasonableness for transferring freight from one truck to another. The platform represented by this logistic server coordinates transports. To allow for cooperation among logistic operators two major aspects must be considered: The information exchange and the matching process.

Information Exchange: The logistic server can be accessed via an IP based connection to transfer the required information. Thereby, an appropriate security and authentication scheme should be used, which is out of scope of the current work. The information can be encapsulated using e.g. the XML standard as illustrated in the following:

```
<?xml version="1.0" encoding="UTF-8">
 <driverstatus>
 <remaining>4 hours</remaining>
 <timestamp>2011-07-10T16:00:00Z</timestamp>
 </driverstatus>
 <truck id=12345>
   <type>dry cargo</type>
   <capacity>10 tons</capacity>
   <location>
     <name                    latitude=-10.903719
longitude=38.517106>Tunduru</name>
   </location>
 </truck>
 <freight>
   <order id=98765>
     <type>dry cargo</type>
     <capcity>4 tons</capacity>
     <destination>
          <name               latitude=-6.8159141
longitude=39.2801404>Dar es Salaam</name>
     </destination>
   </order>
 </freight>
```

The *driverstatus* tag holds current information about the driver. To calculate an appropriate TP the most relevant one is the remaining work time before a break must be taken. This is required in order to provide participating trucks with more reliable information about the estimated time of arrival. Other useful information would be e.g. contact details like a telephone number. The *truck* tag has and unique identifier and contains information about the type, capacity, and the current location. The *order* tag also has an identifier and holds information about the current freight like the type, size and the destination. This can be further extended by e.g. transport costs or price, time windows for delivery, etc. When matching candidates are found they need to be informed about the TP (*transshipmentpoint*), with whom to meet (*truck*), when in time, what to transfer (*transfer*). An example of such a confirmation message is illustrated here:

```
<?xml version="1.0" encoding="UTF-8">
<transshipinformation>
  <transshipmentpoint>
    <location>
      <name                   latitude=-10.903719
longitude=38.517106>Tunduru</name>
    </location>
  </transshipmentpoint>
  <truck id=23456>
    <ETA>2011-07-10T18:51:00Z</ETA>
  </truck>
</transshipinformation>
<transfer>
  <order id=98765>
    <type>dry cargo</type>
    <capcity>4 tons</capacity>
    <destination>
      <name                   latitude=-6.8159141
longitude=39.2801404>Dar es Salaam</name>
    </destination>
  </order>
</transfer>
```

As mentioned before, the communication is IP based and therefore a standard web interface can be used at the server side for information and location updates. Based on the clients' updates possible freight consolidations will be calculated using a matching process at the server side.

Matching Process: During this process, illustrated in Fig 2, the information provided by the clients is used to find possible freight consolidations, whereby additional costs for the transshipment process and the drivers' breaks must be considered. Only if the total costs including transshipment are below the common transport costs (direct delivery) a confirmation message is sent to the clients concerned. The goal is to make the best decision for each truck: drive on to the current destination or meet another vehicle at a new destination. The according steps are as follows:

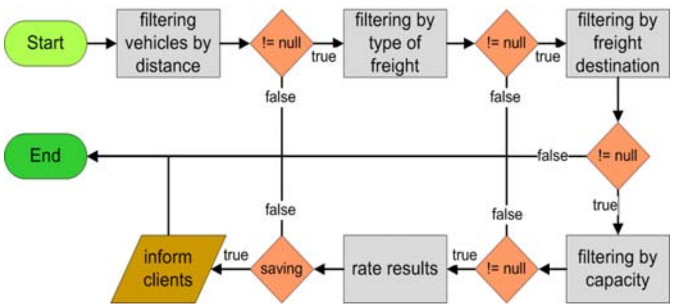

Fig. 2. Simplified Matching Process

a) Filtering by distance: All trucks are selected which are able to reach each other within a certain amount of time, because meeting with vehicles outside this radius is usually too expensive.
b) Filtering by type: Only freight of the same type can be consolidated. The type of the freight within the message is selected out of a global list of types to ensure matching compatibility.
c) Filtering by destination: If the destinations are equal or close to each other possible candidates are further processed. This distance depends on the remaining distance to the farthest/longest destination. Therefore a shortest/fastest routing metric is applied.
d) Filtering by capacity: It is verified if the whole freight of both vehicles fits into one of the candidates' trucks. For the actual transshipment the vehicle with the lower volume is unloaded to save transfer costs.

e) Rate results: Out of the remaining candidates the best solution must be selected. Therefore, a weighting function is used which will be explained in the following. The resulting costs are compared with a direct delivery and the best one (if any) is selected.

f) Inform clients: For the best match the TP found by the weighting function is transferred including additional information.

$$TPCost_{ti} = d_{ti,TP} \times costs_{per\ km} + tt_{ti,TP} \times hr$$
$$TransshipCosts = constant_{type} \times volume \times hr$$
$$RouteCosts = d_{TSP(o_1,..o_k)} \times costs_{per\ km} + tt_{TSP(o_1,..o_k)} \times hr$$
$$TotalCosts_{ti,tj} = TPCost_{ti} + TPCost_{tj} + TransshipCosts + RouteCosts$$

Fig. 3. Formulas for cost estimation

The mentioned weighting function provides the quality of a possible transshipment action. First, the best possible TP is determined wherefore the distance for $truck_i$ ($d_{ti,TP}$) and the estimated travel time for $truck_i$ ($tt_{ti,TP}$) are considered. To these values the transshipments costs are added. Thereby, the costs per km can be neglected, but the drivers' hourly rates (*hr*) are fully charged. The transfer time depends on the type of freight and its size (volume or weight). Finally, the costs of the new route to the destination(s) are calculated. To calculate an appropriate route the travelling salesman problem (TSP) [10] is solved considering the current orders ($TSP(o_1,...o_k)$). On one hand the resulting distance is multiplied with the costs per km and on the other the estimated time for the distance is multiplied by the hourly rate. The resulting $TotalCosts_{ti,tj}$ are than compared with the costs of a direct transport using separate vehicles and other possible candidates' $TotalCosts_{ti,tl}$. Finally, the best solution (if any) is chosen.

C. Simulation Environment

Based on previous work [13],[14] we extended the simulation environment for the proposed use case. It was already possible to utilize OpenStreetMap (OSM) data [15] as simulation basis to provide realistic road networks and vehicle movement. In contrast to the road network of a single city a country for large distance transport (SE 1) is applied. The closest accessible road next to an OSM city name is used as origin and destination location. The TPs are aligned on a grid of specific size also using the closest accessible road. If there is no road within a grid cell or if the location would be to close to a city no TP will be placed (SE 2). For our demand model (SE 3) we assumed that 35% of the transports in Tanzania are national and therefore an according amount of the destination and origin cities where chosen randomly. With respect to [1] out of the remaining 65%, 80% of two-thirds (imports) of the orders depart from Dar el Salam and 10% from Tanga. 50% of one third (exports) of the destinations are also Dar es Salam and 25% Tanga. The remaining origins and destinations are generated randomly. Instead of buses transporting passengers, trucks have been added with an according capacity, a freight type and speed restrictions (SE 4). The driver has been modelled within the truck class by parameters like the maximum work time and the rest time (SE 5). Furthermore, the algorithm and matching process as proposed have been integrated within the simulation environment. At each simulation step a truck can drive to its current destination, wait for another truck for transshipment, transfers freight, or needs a break because the maximum work time is exceeded. Every second step the algorithm is executed whereby the required information of each truck is transferred to a central server which is responsible for the matching process. Besides the presented algorithm we implemented a generic transport model, whereby every truck is driving directly towards the destination also respecting the maximum work time and speed restrictions, but without cooperation. Therefore, it is possible to evaluate the cooperative approach according to parameters like the trucks and orders travel -, transshipment -, and rest time as well as the covered distances.

IV. Evaluation

Fig. 4. Road network and cities of Tanzania

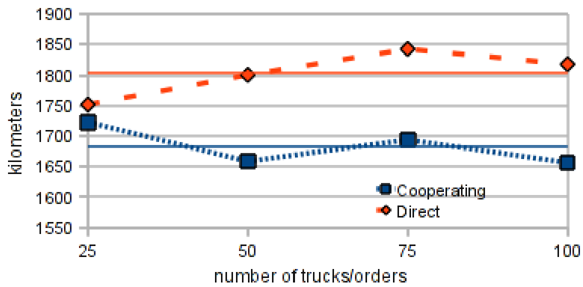

Fig. 5. Distance covered by trucks

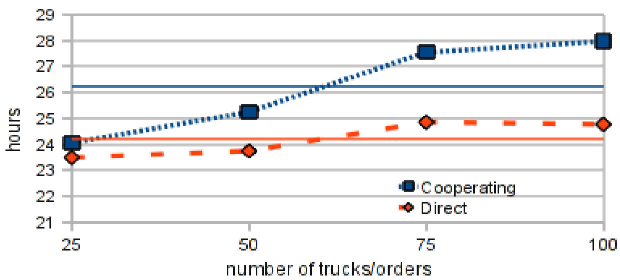

Fig. 6. Orders' delivery time

The simulation environment was set up using the OSM data of Tanzania consisting of the road network as illustrated in Fig. 4. We selected 23 cities and 161 additional TPs were added automatically on a grid with a distance of around 75 km or 40 km to a city. We conducted up to 10 different simulation runs based on our demand model with 25, 50, 75 and 100 orders for the proposed cooperative algorithm as well as for the direct delivery model. The orders were added to the simulation during run time within an interval of about 24 hours. Due to simplicity reasons a truck was created with each order and returns to its origin after his transportation task is completed. Furthermore, only one type of freight was used. Not considered so far are delays caused by incidents like truck breakdowns or temporary impassable road segments, which is left for future work. A simulation step was set to 10 minutes in real time resulting in a location update and matching process execution every 20 minutes. The radius for the initial distance filtering was configured as the distance that could be covered within 1 hour depending on the speed limit of the current road or the truck's maximum speed. The average distance of the orders (directly transported: 879 to 917 km) as well as the average speed of the trucks observed (both approaches: ~38 km/h), reflects the findings in [3]. Therefore, the utilized model comes close to realistic conditions. The average covered distances for both approaches are illustrated in Fig 5. By using the cooperative approach the average savings in distance (including the way home) were 29 km for 25 orders, because the number of matches was quite small. For 100 orders the average saved distance was 161 km. This leads to total savings for all trucks from 725 km (25 trucks) to 16,116 km (100 trucks). The total covered distances for the direct transport were 43,794 km (25 trucks) and 181,795 km (100 trucks). As illustrated in Figure Fig. 6, the average time until delivery differed up to 13% in favour for the directly transported freight. The average time over all instances was 24.2 hours (direct transport) and 26.2 hours (cooperative transport). Also the distance covered by freight raised by up to 11% due to the detours to the TPs. The average time, spend for unloading and transhipment was up ~20% higher utilizing the cooperative approach. Nevertheless, the average total time decline by up to ~8% until every truck returned.

V. Conclusion

In this paper a novel cooperative distribution approach was presented which has been integrated into a platform for logistics and transport. It could be shown by simulation that the cooperative approach enhances freight distribution concerning the total covered distances and without a major impact on the delivery times in long distance road transport. Furthermore, the presented scheme supports a dynamic mode of operation as vehicles can be already on the move and still have the opportunity for cooperation. Hence, no computation intensive scheduling scheme is used where an optimal route and occupancy rate is calculated in advance and must be discarded when an incident or vehicle breakdown occurs which is favourable when unreliable conditions are involved. In contrast to the transportation task the proposed platform can be of assistance to identify major transport routes and possible bottlenecks within freight distribution. Therefore, it can also support decisions for future building investments to improve and extend the existing infrastructure. As mentioned before, several restrictions need to be modelled and evaluated in future work like, changing road conditions, vehicle breakdowns, or other delays caused by different reasons. Another challenge is the integration of rail bound transportation into the existing system to enable multi-modal logistics. Additionally, a fair price scheme needs to be developed when only a part of the total distance is covered by one truck to leverage cooperation between different companies or individuals.

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