SIMULATION OF RETURNABLE TRANSPORT ITEM SYSTEMS

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ABSTRACT

This paper provides a short description of the COMPASS-model which is a concept for the simulation of multiway systems. The focus of the COMPASS-model is to offer an opportunity to investigate the effects of redistribution strategies on logistic and monetary values in a system of returnable transport items (RTI). The modeling concept consists of five modules: topology, system load, distribution, redistribution, cost. It includes the integration of highly sophisticated evolutionary algorithms for the optimal solving of complex capacitated vehicle routing problems (CVRP) which are typical for RTI-systems. The results of first experiments with a COMPASS-based prototype are repeated. They reveal some basic regularities in RTI-systems.

1 RETURNALBE TRANSPORT ITEM SYSTEMS

Returnable transport items (RTI) are packaging items which can be used repeatedly, sometimes up to 200 and more cycles. There is a great variety of forms and constructions - e.g. pallets, boxes, containers, etc. - which are still playing an important roll in the field of packaging and logistics.

An RTI system consists of a stock of returnable transport items and a logistic chain. The characteristic a RTI system is the redistribution of the empties after being used. Synonyms for RTI systems are "pools" and "multiway systems". In the late eighties and early nineties they were held to be effective means of reducing ecological impacts of transportation and the exchange of goods. Today the situation is different. Globalization and worldwide competition have entailed an enormous cost pressure which also applies for multiway systems. Therefore economic aspects have replaced the ecological arguments.

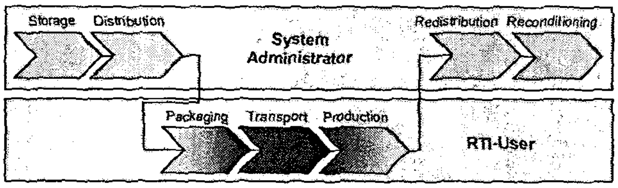
The main active partners in RTI systems are the system administrator and the RTI-users. The system administrator is the owner of the whole stock of RTIs, he is responsible for the distribution and redistribution of the empties. The RTI-user is his customer. He is responsible for the RTIs as long as he uses them.

It is necessary to have a short look on the different processes in the multiway system. Following the way of a RTI through the whole multiway system one can detect seven basic processes, which recur cyclically.

- The system administrator holds a stock of RTI ready.
- If a customer conveys a demand to him the system administrator delivers the requested number of empties to him.
- The customer makes use of the RTIs by filling them with his products and
- sending them to his own customer and partner in the logistic chain.
- The consignee takes the goods out of the RTI and gives notice to the system administrator, that a stock of empties is ready for redistribution.
- Now the system administrator can fetch the RTI, take them back to his own depot and
- recondition them. This means that used RTI must be checked, repaired, and cleaned in order to guarantee that the RTIs are in perfectly sound condition.

Thus the multiway system can be divided into two totally different zones.

- The processes of storage, distribution, redistribution, and recondition are controlled by the system administrator.
- The processes connected with the actual use of the RTIs - that is packaging and transportation between sender and consignee - are controlled by the RTI-users. The system administrator has only small or no influence.



Up to now researchers have concentrated their focus onto the processes which take place under the responsibility of the users (e.g. [1], [2], [3], [4], [5]). In contrast to this state of the art we started our modeling concept with the question how the actions of the system administrator can be described in a formal way and how the control of the redistribution of empties can be modeled.
The system administrator has to take his own economic benefit into account. But how is such a system to be organized and planned? Important questions are:

- What impact does the location of the depot have on the medium transport distance?
- How is the total stock of RTI to be dimensioned if the system load can not be regarded as constant?
- Which redistribution strategy should be applied?

In the course of an actual research project of the Department of Logistics - as part of the Collaborative Research Center "Modeling of large logistics networks" (SFB 559) at the University of Dortmund (Germany) - a model of this situation was developed, called "COMPASS" - Cycle Optimization in Multiway Systems by Planning, Analysis, and System-Simulation. The major aims are

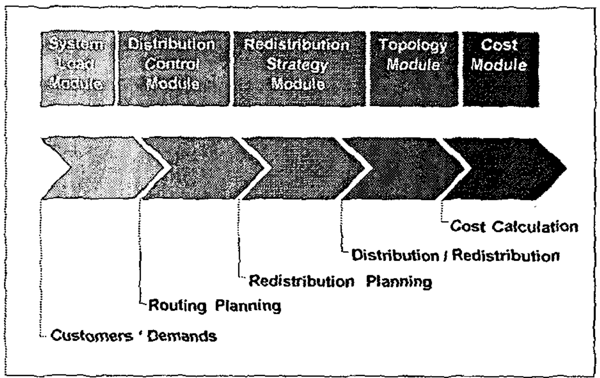
- to find criteria for the control of redistribution processes and to model them,
- to detect and calculate the effects of different redistribution strategies on the basic logistic quantities - total RTI stock and cumulated transport distance - and the total cost of the whole system, and
- to determine how these effects depend on initial conditions such as the location of the depot, oscillation of the system load and the number of RTI-users.

For this purpose it was necessary to extend existing CVRP descriptions and integrate the solving algorithm into a simulation model.

2 THE MODEL

The COMPASS-model consists of five modules which correspond with the five basic business processes of the system administrator. These are

- the system load model for the modeling of the demands of the RTI-users,
- the distribution module for the modeling of the distribution planning,
- the redistribution module for the modeling of the redistribution strategy,
- the topology module for the modeling of the physical transportation processes, and
- the cost module for the calculation of the system cost.



Beginning with the topology module these five basic elements shall be described in short:

2.1 The Topology Module

The topology module is based on the idea that logistic systems can be regarded as networks of relations and intersections. On the relations transport means can operate and fulfill the exchange of goods. The intersections represent the active partners of the multiway system, i.e. the system administrator and the RTI-users.
An RTI-user consists of two stocks of RTI, one for the RTI before use and one for the empties. Between the user i as a sender of goods and his own customer - the consignee - a flow of RTIs $\lambda_i(t)$ and a flow of empties $\lambda_{R,i}(t)$ can be defined. In the same way the replenishment can be modeled as a flow of RTI $\lambda_{D,i}(t)$ from the depot of the system administrator to the user and a flow of empties $\lambda_{RD,i}(t)$ from the user back to the depot.
In order to control the exchange of RTIs order policies have to be implemented. These algorithms determine how the RTIs-users control their replenishment.

2.2 The System Load Module

The flow of RTIs $\lambda_i(t)$ and the flow of empties $\lambda_{R,i}(t)$ form the system load. It is possible to use actual data if they can be derived from a company's data processing. But often it is necessary to build up a model of the exchange of RTIs. The COMPASS-model uses the principles of time sequence analysis in order to create the demands and orders of the users. With the help of the "Berliner Verfahren" it was possible to form the following formulas which represent the flow of RTIs and empties.

$$\lambda_i(t) = \lambda_{M,i} \cdot \begin{pmatrix} 1 \\ + \frac{x_i t}{\vartheta_H} \\ - a_i \cdot \cos\left(\frac{2\pi t}{\vartheta_H}\right) \\ - \frac{b_{W,i}}{2} + \left(t - \left[\frac{t}{w-1}\right] \cdot w - 1\right) \cdot \frac{b_{W,i}}{w-1} \\ + rd_i \cdot (2Rnd_i(t) - 1) \end{pmatrix}$$

$$\lambda_{R,i}(t) = \lambda_{RM,i} \cdot \begin{pmatrix} 1 \\ + \frac{x_{R,i}(t - T_{a,i})}{\vartheta_H} \\ - a_{R,i} \cdot \cos\left(\frac{2\pi(t - T_{a,i})}{\vartheta_H}\right) \\ - \frac{b_{RW,i}}{2} + \left(t - \left[\frac{t}{w-1}\right] \cdot w - 1\right) \cdot \frac{b_{RW,i}}{w-1} \\ + rd_{R,i} \cdot (2Rnd_{R,i}(t) - 1) \end{pmatrix}$$

$\lambda_i(t)$:	flow of RTIs
$\lambda_{M,i}$:	mean flow of RTI in the beginning of the experiment
x_i:	increase of the RTI flow [% per year]
a_i:	amplitude of the oscillation of the RTI flow because of seasonal influence [%]
$b_{W,i}$:	amplitude of the weekly oscillation of the RTI flow [%]
rd_i:	amplitude of the random oscillation of the RTI flow [%]
$\lambda_{R,i}(t)$:	flow of empties
$\lambda_{RW,i}$:	mean flow of empties in the beginning of the experiment
$x_{R,i}$:	increase of the flow of empties [% per year]
a_R:	amplitude of the oscillation of the flow of empties because of seasonal influence [%]
$b_{RW,i}$:	amplitude of the weekly oscillation of the flow of empties [%]
$rd_{R,i}$:	amplitude of the random oscillation of the flow of empties [%]
$T_{a,i}$:	mean duration of the use per cycle [d]
θ_H:	duration of the experiment (model time)
w:	workdays per week
$Rnd_i(t)$; $Rnd_{R,i}(t)$:	random values [0; 1]

2.3 The cost module

In order to calculate the system cost the idea of activity based costing is integrated into the model. Each logistic process is regarded as an activity which creates a cost category of its own. In summa ten different cost categories proved to be adequate. These are

- Storage cost
- Handling cost
- Transport cost
- Transshipment Cost
- Reconditioning Cost
- Disposal Cost
- Procurement Cost
- Capital Cost
- Administration Cost
- Rents and cycle fees.

These cost categories comply with the German VDI-guideline 4407.

2.4 The distribution module

In contrast to linear distribution chains RTI systems are closed loop systems. In ordinary one-way distribution systems the main question is how goods can be delivered with a certain number of trucks in the most efficient way. The optimization criterion is the cumulative transport distance of the necessary tours in terms of kilometers or money. As the delivery of goods is only triggered by the customers the number and geographic positions of the tour stops are determined by the customer orders. Therefore the tour stops generally form the problem and cannot be influenced or changed by the distributor. In the relevant literature such a distribution problem is called "Capacitated Vehicle Routing Problem" (CVRP).

Interdisciplinary cooperation within the Collaborative Research Center "Modeling of large logistic networks" (559) of the University of Dortmund offered the opportunity to integrate highly sophisticated CVRP-solvers into the COMPASS-model. For this purpose the Chair of System Analysis from the Department of Computer Science of the University of Dortmund (Prof. H.-P. Schwefel) provided the "vrp6", a CVRP-solver specialized for routing problems in complex networks.

The vrp6 and its interface to the COMPASS-model was designed by Andreas Reinholz and Dr. David Mester, a guest researcher of the chair of Systems Analysis. The search strategy of the vrp6 is written in C++ and the graphical user interface in Visual Basic.

Regarded from the COMPASS-model the CVRP solver is realized as a black box which is encapsulated through a well defined interface. This approach has the advantage that the vrp6 could easily be replaced by other optimization methods or commercial routing software which are using geographical databases based on real road networks.
The search strategy of the vrp6 can be described as a hybrid Evolutionary Algorithm, that combines a (1+1)-Evolutionary Strategy [13] with different problem specific Neighborhood Search methods.
The (1+1)-Evolutionary Strategy uses four different mutation operators and a special disruption scheme to prevent preliminary convergence in bad local optima.
The hybridization of Evolutionary Algorithms with Neighborhood Search methods and problem specific operators is a general applicable procedure to integrate domain dependent information in Evolutionary Algorithms. Many other applications and powerful problem solvers show that this is an elegant and easy way to improve the performance and reliability of Evolutionary Algorithms (e.g. [9], [10], [11], [16], [17], [18], [19]).
The vrp6 was designed to produce high quality solutions for large scale CVRP and VRPTW (VRP with Time Windows) up to 1000 customers. For this purpose it is one of the best implementations so far. For nearly all benchmark problems out of the standard literature it was able to find best known solutions (e.g. [12], [15], [16]).

2.5 The redistribution module

The redistribution of empties in a multiway system can not be described as an ordinary CVRP with pickup and delivery because the redistribution process is not only triggered by the customers. The closed loop structure and additional degrees of freedom in the system lead to a higher level of complexity. Therefore the vrp6 had to be extended with an upper strategy level in which decisions are made according to a chosen redistribution strategy.
In order to work the extension needs a formal representation of the possible redistribution strategies. This can be regarded as an algorithm which indicates if the empties at a certain customer's should be picked up or not. Each picking up process costs money for the system administrator but it also entails benefits. The redistribution algorithm must be designed in order to compare the cost of the picking up with its benefits. In order to solve the problem six redistribution indices could be defined, one for each redistribution strategy which is known to be in practice. The range of different strategies relevant for the control of the redistribution of empties could be confined to the number of six as a result of empirical research work.
Each redistribution index has the form of a fraction with the benefits of the redistribution of a stock of empties at a certain customer i in terms of money as numerator and the redistribution cost as denominator. If the value of a redistribution index is greater than 1 the benefits surpass the cost. In consequence this customer i should be visited and the empties should be picked up.
The integration of the customer i in the tour plan found by the vrp6 is done by a CIS (cheapest insert) procedure in the following manner: Starting from a tour plan found by the vrp6 in the distribution module, the CIS procedure inserts the service of customer i into the current working tour plan with cheapest additional cost, if the benefits of this insertion surpass the cost. This procedure is continued until no further successful insertion can be done.
This two-stage optimization process consisting out of vrp6 and CIS is repeated until no further improvement can be found or a certain runtime limit is exceeded.
Again the two-stage problem solver for this extended CVRP with pickup and delivery was integrated in the COMPASS-model as a black box with a well defined interface. The interaction between the COMPASS-modules and the vrp6- and CIS-algorithm is determined by the work of the six different redistribution indices mentioned above. These are:

- Capacity oriented redistribution index (R_C)
- Delivery oriented redistribution index (R_D)
- Circle time oriented redistribution index (R_T)
- Wastage oriented redistribution index (R_W)
- Bottleneck oriented redistribution index (R_B)
- Order oriented redistribution index (R_O)

The different redistribution strategies and their modeling in the form of redistribution indices is described by Jansen and Krabs [6].
It is self-evident that it cannot be decided in the sense of a general rule which redistribution strategy is the best one. It depends on the branch of industry, the organizational background of the multiway system, the exchange mode, the costing and stock-taking system of the system administrator, and the mode of interaction between the business partners. But how to decide? We suggest that the system administrator should always follow all the six strategies simultaneously building up a total redistribution strategy out of a combination of the six basic criteria.

$$R_i(t) = \alpha_{C,i}R_{C,i}(t) + \alpha_{D,i}R_{D,i}(t) + \alpha_{T,i}R_{T,i}(t) + \alpha_{W,i}R_{W,i}(t) + \alpha_{B,i}R_{B,i}(t) + \alpha_{O,i}R_{O,i}(t)$$

$R_i(t)$:	Total redistribution index
$R_{C,i}(t)$:	Customer oriented redistribution index
$R_{D,i}(t)$:	Delivery oriented redistribution index
$R_{T,i}(t)$:	Circle time oriented redistribution index
$R_{W,i}(t)$:	Wastage oriented redistribution index
$R_{B,i}(t)$:	Bottleneck oriented redistribution index

$R_{O,i}(t)$:	Order oriented redistribution index
$\alpha_{C,i}$:	Customer oriented coefficient
$\alpha_{D,i}$:	Delivery oriented coefficient
$\alpha_{T,i}$:	Circle time oriented coefficient
$\alpha_{W,i}$:	Wastage oriented redistribution index
$\alpha_{B,i}$:	Bottleneck oriented coefficient
$\alpha_{O,i}$:	Order oriented coefficient

The values of the redistribution coefficients signify how much importance the system administrator attaches to each single criterion. They have positive values $\alpha_i > 0$. With this a redistribution strategy can be described as a set of coefficients

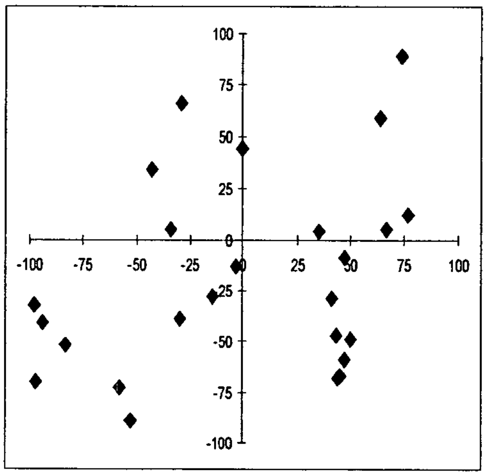
$$(\alpha_{C,i};\ \alpha_{D,i};\ \alpha_{T,i};\ \alpha_{W,i};\ \alpha_{B,i};\ \alpha_{O,i}).$$

Up to now the impacts of other features in multiway systems - such as the exchange mode, the costing system, or the stock-taking - on the optimal redistribution strategy have not yet been investigated. The modeling concept of the redistribution strategy proved to be a promising starting point for further research work. A corresponding computer program for the investigation of multiway systems was developed at the Department of Logistics in order to run first experiments.

3 EXPERIMENTS

From a real multiway system of a great company in the electronic business a model RTI system was derived by means of abstraction. The model RTI system consists of 25 customers and a system administrator, the distribution area is square 200km by 200km. Each customer is characterized by his Cartesian coordinates and his demands and order policy, i.e. the system load.

	x	y
A	77	12
B	44	-68
C	-94	-41
D	74	89
E	-3	-13
F	64	59
G	50	-49
H	-53	-89
J	0	44
K	-98	-32
L	-14	-28
M	45	-67
N	47	-9
O	35	4
P	67	5
Q	-97	-70
R	-29	66
S	43	-47
T	-34	5
U	-30	-39
V	-43	34
W	41	-29
X	47	-59
Y	-83	-52
Z	-58	-73



Three experiments are performed:

- Different locations for the depot of the system administrator are examined.
- An additional customer is integrated into the RTI-system.
- Different amplitudes of system load oscillation are analyzed.

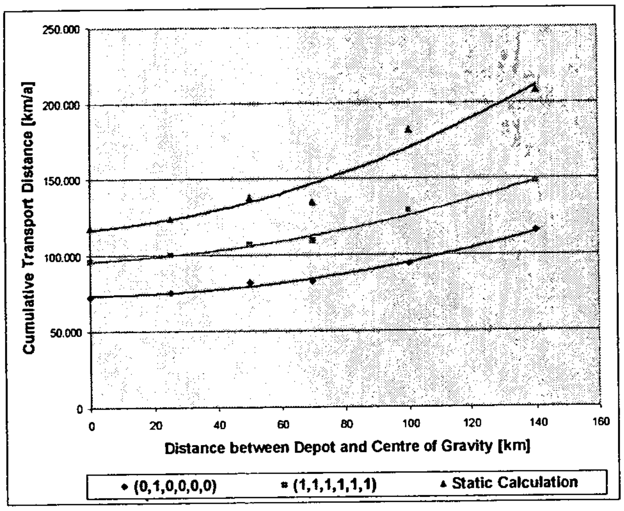
Each experiment is run with the redistribution strategy (0,1,0,0,0,0), i.e. the delivery oriented redistribution strategy. This means that the system administrator only tries to minimize transport cost by means of the reduction or avoidance of deadhead mileage and empty runs. This is a quite important objective as the actual percentage of full runs versus total runs in Germany is 78% with owner-hauliers and 70% with private freight [7]. In the field of multiway systems deadhead mileage can be avoided if delivery and redistribution are strictly combined: The same truck which delivers new RTIs to the customer takes the empties back to the depot. The result is a kind of commuter traffic not only between two partners but also in a complex network. Here the transport distances are minimized as no extra tour for the redistribution of the empties is necessary.
A second run is performed with the redistribution strategy (1,1,1,1,1,1). This is the most complex strategy which takes all the six criteria for the control of redistribution transport processes into account. Therefore this redistribution strategy is called multi-criteria redistribution strategy.
Thirdly the results of the simulation experiments can be compared with the results which can be derived by static calculation.

4 RESULTS

The first experiment showed that the cumulative transport distance S is proportional to the square of the distance d between the location of the depot and the center of gravity of the RTI-system.

$$S \sim d^2$$

The multi criteria redistribution strategy requests more transport effort than the delivery oriented redistribution strategy, but requires a smaller stock of RTI. In terms of money (1,1,1,1,1,1) proves to have an advantage of ca. 6% over (0,1,0,0,0,0).



For the second experiment a new customer was integrated into the multiway system requiring an additional stock of RTI and additional transport kilometers. The experiment proved that a multi criteria redistribution strategy leads to a more stable function of the multiway system than the delivery oriented strategy. This means that by the help of (1,1,1,1,1,1) 50% of the increase of total cost can be avoided in comparison to (0,1,0,0,0,0).

The third experiment compared the effects of different amplitudes a of system load oscillation (0%, 20% and 40% of the mean). If system load is not constant then - in comparison to constant system load - an additional stock N_{add} is necessary. It is not astonishing that we found

$$N_{add} \sim a$$

5 FINAL REMARKS

It is not possible to describe the COMPASS-model in detail in this conference proceedings. The reader will find a full report in [8].

With the COMPASS-model it is possible to analyze the effect of redistribution strategies in multiway systems. But the level of abstraction is high. This means that at the moment present many facts and requirements important in existing RTI-systems cannot completely be taken into account. Thus we have but scratched the surface. But the results we could find are encouraging.

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