Quantifying the Effect of Flexibility and Information Sharing in Transportation Planning

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Abstract. In this paper, we analyze the effect of information sharing between a wholesaler and a transport company in the Norwegian grocery supply chain. The planning process of each company is formulated as a set covering problem, where the input data of the transport company depends on the optimal solution of the wholesaler model. Information sharing is modeled through controlling which information from the wholesaler model is sent to the transport company model. We define three different cases of information sharing and introduce two types of flexibility, namely the abilities to deviate from the planned delivery date and selected routes. We use real-world data to calculate the effect of information sharing for the different cases. Our results indicate that the benefits from information sharing are limited if there is no flexibility in the system.

Keywords: Information Sharing · Transportation Planning · Flexibility · Set Covering Problem

1 Introduction

In the Norwegian grocery industry, transportation cost represent approximately 33% of the wholesalers' total operating cost [16]. Improving transport efficiency can therefore lead to improved profit margins. According to Norwegian transport companies and their partners, limited information sharing is the main obstacle to increased efficiency [1]. However, the literature has a nuanced view on the value of information sharing: one stream of literature considers (increased) sharing of information as generally positive for the supply chain, but acknowledges the trade-off between value of information sharing and costs due to added complexity, see e.g. [7, 25]. Other authors state that the potential benefits are highly limited, mainly due to complexity, cost and risk [18]. Within transportation planning, sharing information horizontally, i.e. among transport companies, for the purpose of collaborative planning is examined. A recent example is [21], studying a collaborative vehicle routing problem where the transport companies have different attitudes towards information sharing. See also [12] for a review on collaborative vehicle routing. Despite the interest in information sharing, the utilization of shared information has not received much attention in the literature, notable exceptions are [20, 17, 22].

Daily demand in the grocery industry is uncertain [10], but exhibits a predictable, repetitive weekly pattern. This weekly pattern is characterized by daily variations in demand, with demand increasing towards the end of the week [6]. Promotions disturb the daily demand pattern and thus affect its predictability [11], but often lead to a predictable increase in demand for the promotional products. However, promotions are known well in advance of the promotion period [19]. Combining the knowledge of a planned promotion period with the weekly demand pattern allow the wholesaler to predict the cargo volumes that need to be transported during a given week.

Transport companies often receive information regarding the cargo volume that has to be transported less than 24 hours before departure [14]. Earlier access to this information might improve transport planning and consequently reduce the cost of transportation. This paper analyses how the cost of transportation is affected by a Norwegian grocery wholesaler sharing cargo information with the transport company. To account for the different decision makers and to study the effect of information sharing, we model the decision processes of both the wholesaler and the transport company as independent optimization problems, where the outcome from the wholesaler's planning problem becomes input to the transport company's planning problem. We then investigate how a transport company can utilize the shared information under two types of flexibility: First, we consider delivery flexibility, i.e. the ability to change the delivery time of cargo. The second type of flexibility is route selection flexibility, where we allow the transport company to freely choose a route from a set preselected routes.

The remainder of this paper is organized as follows: in Section 2 we describe the planning process for the wholesaler and the transport company. We also introduce how information is shared between the two actors and how the types of flexibility can be exploited to reduce the cost of transportation. The mathematical model formulations are presented in Section 3. Case data and computational results are provided in Section 4. We conclude in Section 5.

2 Transportation Planning and Information Sharing

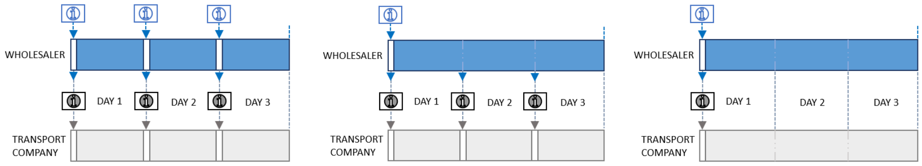
The grocery supply chain we consider in this paper belongs to one of the largest grocery companies in Norway, covering both wholesale and retail activities. The physical distribution of goods is organized according to a typical single-channel structure [24]: a third-party carrier transports the goods from the wholesaler to the retailer. The companies plan the distribution of goods from the wholesaler to the retail stores in two main stages: The first stage is carried out by the wholesaler, who is responsible for the general and mid-term planning in the form of a tactical route plan. The tactical route plan specifies the available routes that are supposed to be used for the distribution of goods. These tactical routes are determined using average demand data for given regions, taking into account frequency requirements as well as delivery time windows at retails stores. The objective is to minimize the delivery costs while ensuring a high truck utilization, see also [15]. Due to the short planning horizon, we assume the tactical route plan to be constant in the remainder of the paper.

The second planning stage is the operational distribution planning carried out by both the wholesaler and the transport company. The wholesaler determines the amount of cargo to be transported the following day and the set of tactical routes that the transport company can choose from. Due to requirements of the retail stores, e.g. delivery time windows, tactical routes are usually specific to the day of departure, i.e. a route planned for being used on Mondays can only be selected on Mondays. The transport company then allocates goods to trucks and trucks to routes. The transport company can also select to serve shorter subroutes of the tactical routes, e.g. if actual demand on a tactical route exceeds the capacity of a truck. Note that the objective for the two companies is different: The transport company wants to minimize the number of trucks used to transport the goods, whereas the wholesaler minimizes the cost of the transport volume plus a penalty for deviating from a given target volume. This penalty provides an incentive to the wholesaler to ship more or less the same volume each day, facilitating a more efficient resource utilization [7].

Formulating the wholesaler and transport company's decision problems as single, integrated optimization problem with multiple objectives might result in better distribution plans. This is due to the fact that the information of both companies would be captured in the same model. However, this approach implies a single decision maker as well as the availability of full information. Neither of these assumptions holds in case of the problem considered in this paper.

To study the value of information sharing between the wholesaler and the transport company, we focus on operational distribution planning. We distinguish between three different information sharing cases. The cases differ in how the wholesaler plans distribution and shares tactical routes and cargo volume with the transport company. The different cases are illustrated in Figure 1. The planning horizon is considered to be one week. In the first information sharing case (DD), the wholesaler plans distribution on a daily basis. This information is shared with the transport company each day, which can only plan one day ahead. In the second case (WD), the wholesaler plans distribution for the entire week, but still shares routes and volumes on a daily basis only. The third case (WW) considers the situation where the wholesaler shares the distribution plan for the entire week with the transport company. This is also the only case where the transport company can plan for the entire week.

The daily distribution plan resulting from the operational distribution planning combines the chosen subset of tactical routes with the actual demand. However, actual demand may exceed the demand that was used to determine the tactical routes. In this case, the transport company may have to deploy more than one truck on the route, each serving a subset of the retail stores along the route. A possible consequence of this is a reduced utilization of the available trucks.



(a) Daily - Daily (DD) (b) Weekly - Daily (WD) (c) Weekly - Weekly (WW)

Fig. 1. Three different combinations of planning and information sharing

We introduce two types of flexibility and study their effect on the transportation cost: The first type of flexibility is delivery flexibility, i.e. here defined as the ability to deviate from the originally planned delivery date. Delivery flexibility can only exploited when planning for the entire week and only for goods that can be stored without deteriorating. We distinguish between three groups of goods, namely non-storable (NS), promotional storable (PS) and ordinary storable (OS) goods. Non-storable goods must be transported in accordance to planned delivery date. The wholesaler is allowed change the delivery date of PS goods to an early point in time for the WD and WW information sharing cases. The transport company can postpone the delivery of OS goods in the WW information sharing case. Changing the delivery date can only happen within the planning horizon of one week.

Route selection flexibility allows the transport company to choose different routes than the ones selected by the wholesaler. In the base case, the transport company can only use the wholesaler's selected routes for each given day. Under conditional route selection flexibility, the transport company can choose from the routes in the wholesalers has selected, irrespective of which day they were supposed to be driven. In the case of an unconditional route selection flexibility, the transport company may choose any route from the set of tactical routes, independently of choices made by the wholesaler.

3 Model Formulations and Solution Approach

For transportation planning, routing problems are the most common group of quantitative models. The Vehicle Routing Problem (VRP) is one of the most well-known and studied transportation routing problems, see [13, 26] for excellent overviews of the problem, extensions and solution methods.

A common way to model a VRP is using a set covering formulation, see e.g. [3, 23, 2]. The set covering formulation is very general and constructed to find the routes that will satisfy the delivery requirements at minimum cost. Two main approaches for generating the set of routes to choose from can be distinguished: The first approach entails the iterative generation of routes on-the-fly, e.g. through column generation [9, 4]. See [8] for a thorough literature review of the advancement of column generation and the use of set covering formulations in VRPs. In the second approach, the set of routes is generated a priori, i.e. before solving the optimization model [5].

We formulate the operational distribution planning problem using two set covering models with a set of a priori generated routes. The model for the wholesaler use the given set of tactical routes. The set of routes used in the model for the transport company depends on the degree of route selection flexibility, but is in general determined by the solution to the wholesaler model.

3.1 Notation

We first introduce the notation for the wholesaler and transport company models:

- Sets

$\mathcal{N}$	Set of retailers
$\mathcal{R}$	Set of available routes
$\mathcal{V}$	Set of trucks
$\mathcal{T}^W$	Set of days in the week
$\mathcal{T}^P$	Set of time periods in the week
$\mathcal{T}_d^D$	Set of time periods in day d, $\mathcal{T}_d^D \subseteq \mathcal{T}^P$
$\mathcal{P}$	Set of breakpoints

- Parameters

A_{ir}	1 if retailer i is on route r, 0 otherwise
B_{rt}	1 if route r can be chosen in time period t, 0 otherwise
C_r^P	Cost of transporting one pallet on route r
C_p^L	Penalty for deviating from daily target demand in breakpoint p
C_r^R	Cost of serving route r
C^{Own}	Cost of using an owned truck
C^{Rent}	Cost of using a rented truck
$\overline{D}$	Daily target demand
D_{it}^{NS}	Retailer i's demand of NS pallets scheduled for time period t
D_{it}^{PS}	Retailer i's demand of PS pallets scheduled for time period t
D_{it}^{OS}	Retailer i's demand of OS pallets scheduled for time period t
E	Number of time periods a SP pallet can be delivered earlier
I_i	Retailer i's inventory size
I_i^0	Retailer i's inventory in the beginning of the week
K_r	Number of consecutive time periods a truck is unavailable if assigned to route r
L	Number of time periods delivery a SO pallet can be postponed
m	Number of owned trucks
Q^V	Truck capacity
α	Share of pallets that can change delivery date
β_p	Allowed number of pallets for breakpoint p

- Variables

$w_{i\rho t}$	Number of pallets for retailer i scheduled for time period ρ with actual transport in time period t
x_{rtv}	1 if truck v leaves in time period t on route r, 0 otherwise
y_{irt}^{NS}	NS pallets for retailer i on route r leaving in time period t
y_{irt}^{PS}	PS pallets for retailer i on route r leaving in time period t
y_{irt}^{OS}	OS pallets for retailer i on route r leaving in time period t
δ_v	1 if truck v is used during the week, 0 otherwise
γ_{it}	Number of SP and SO pallets at retailer i's inventory in time period t
σ_{dp}^{+}	Pallets above target demand on day d for breakpoint p
σ_{dp}^{-}	Pallets below target demand on day d for breakpoint p

Please note that transport requirements such as delivery time windows are already incorporated in the given routes. All retailer demand is specified in terms of number of pallets at the departure time.

3.2 Model Formulations

The wholesaler model and the transport company model have many similarities. We first present the objective function and unique constraints of each model separately before presenting the constraints the two models models have in common.

The Wholesaler Model The unique part of the wholesaler model is given as

$$\min \quad \sum_{d \in \mathcal{T}^W} \sum_{p \in \mathcal{P}} C_p^L (\sigma_{dp}^{+} + \sigma_{dp}^{-}) + \sum_{i \in \mathcal{N}} \sum_{r \in \mathcal{R}} \sum_{t \in \mathcal{T}^P} C_r^P (y_{irt}^{NS} + y_{irt}^{OS} + y_{irt}^{PS}) \tag{1}$$

subject to

$$\sum_{r \in \mathcal{R} | A_{ir}=1} (y_{irt}^{OS} + y_{irt}^{PS}) - \gamma_{it} + \gamma_{i(t-1)} = D_{it-1}^{OS} + D_{it-1}^{PS} \qquad i \in \mathcal{N}, t \in \mathcal{T}^P \tag{2}$$

$$\gamma_{it} \leq I_i \qquad i \in \mathcal{N}, t \in \mathcal{T}^P \tag{3}$$

$$\gamma_{i0} = I_i^0 \qquad i \in \mathcal{N} \tag{4}$$

$$\sum_{i \in \mathcal{N}} \sum_{r \in \mathcal{R}} \sum_{t \in \mathcal{T}_d^D} (y_{irt}^{NS} + y_{irt}^{OS} + y_{irt}^{PS}) + \sum_{p \in \mathcal{P}} (\sigma_{dp}^{-} - \sigma_{dp}^{+}) = \overline{D} \qquad d \in \mathcal{T}^W \tag{5}$$

$$\sigma_{dp}^{+} + \sigma_{dp}^{-} \leq \beta_p \qquad d \in \mathcal{T}^W, p \in \mathcal{P} \tag{6}$$

$$\sigma_{dp}^{+}, \sigma_{dp}^{-} \geq 0 \qquad d \in \mathcal{T}^W, p \in \mathcal{P} \tag{7}$$

$$\gamma_{it} \geq 0 \qquad i \in \mathcal{N}, t \in \mathcal{T}^P \tag{8}$$

The objective function (1) reflects different the wholesaler's two cost incentives. The first term expresses is the penalty cost for deviating from the target transport volume. The unit penalty cost, C_p^L, increases piecewise linearly with breakpoint p. Both the unit penalty cost and the total deviation, given by σ_{dp}, increase with increased deviation from the target demand and contribute to the resulting total penalty cost. The second term represents the cost related to transporting a pallet on a given route. The unit cost of transporting a pallet on route r, C_r^P, is positively correlated with the length of the route.

Retailer inventory balance and restrictions are formulated in constraints (2)-(4). Pallets for non-storable goods (NS) are assumed to be placed in the store at once, therefore the retailer inventory only concerns storable pallets. Constraint (2) is the mass balance constraint for the inventory. Constraint (3) prevents each retailer's inventory size from being exceeded at any time. The retailer's initial inventory at the beginning of the week is defined in constraint (4). Constraints (5) and (6) calculate the deviation from the target transportation volume. The deviation is calculated in constraint (5), whereas constraint (6) limits the deviation variables according to the breakpoints of the penalty function. Constraint (7) and (8) are the non-negativity constraints for the decision variables.

The Transport Company Model Note that the set of available routes $\mathcal{R}$ in the transport company model depends on the information sharing case and the solution from the wholesaler model. The objective function and the unique constraints for the transport company model are given as

$$\min \sum_{r\in\mathcal{R}} \sum_{t\in\mathcal{T}^P} \sum_{v\in\mathcal{V}} C_r^R x_{rtv} + \Big(\sum_{v=1}^{m} C^{\text{Own}} \delta_v + \sum_{v=m+1}^{|\mathcal{V}|} C^{\text{Rent}} \delta_v\Big) \tag{9}$$

subject to

$$Q^V \sum_{v\in\mathcal{V}} x_{rtv} - \sum_{i\in\mathcal{N}|A_{ir}=1} (y_{irt}^{NS} + y_{irt}^{OS} + y_{irt}^{PS}) \geq 0$$

$$r \in \mathcal{R}, t \in \mathcal{T}^P \tag{10}$$

$$\sum_{r\in\mathcal{R}} \sum_{t'=t}^{t+K_r} x_{rt'v} \leq 1 \qquad t \in \mathcal{T}^P, v \in \mathcal{V} \tag{11}$$

$$\sum_{r\in\mathcal{R}} \sum_{t'=t}^{t+K_r} \sum_{v\in\mathcal{V}} x_{rt'v} \leq |\mathcal{V}| \qquad t \in \mathcal{T}^P | (t+K_r) \leq |\mathcal{T}^P| \tag{12}$$

$$\sum_{v\in\mathcal{V}} x_{rtv} \leq |\mathcal{V}| B_{rt} \qquad r \in \mathcal{R}, t \in \mathcal{T}^P \tag{13}$$

$$M_1 \delta_v - \sum_{r\in\mathcal{R}} \sum_{t\in\mathcal{T}^P} x_{rtv} \geq 0 \qquad v \in \mathcal{V} \tag{14}$$

$$\delta_{v+1} - \delta_v \leq 0 \qquad v \in \mathcal{V} \tag{15}$$

$$x_{rtv} \in \{0,1\} \qquad r \in \mathcal{R}, t \in \mathcal{T}^P, v \in \mathcal{V} \tag{16}$$

$$\delta_v \in \{0,1\} \qquad v \in \mathcal{V} \tag{17}$$

The first term of objective function (9) is represents the operational costs of serving the selected routes. Here, route cost reflects the time it takes to complete the route. The second term is the cost of the used of trucks during the week.

Constraint (10) ensures that the capacity of all trucks assigned to a route is larger than the demand on the route. Further, constraint (11)-(13) makes sure that a truck v can only be in use once in each time period t. According to constraint (12), it is not possible to use more trucks than available in the fleet. Constraint (13) is a big M-formulation, which ensures that only feasible x_{rtv} are chosen. Constraints (14) and (15) keep track of which trucks are in use when. Constraint (14) connects δ_v and x_{rtv}, requiring δ_v to be equal to 1 if truck v is in use at least once during the week. Furthermore, constraint (15) is a symmetry breaking constraint, ensuring that the trucks with the lowest index are used first. Constraints (16) and (17) impose binary requirements on δ_v and x_{rtv}.

Common Constraints The following constraints are structurally similar in both models and primarily consider demand. The constraints are here presented in terms of the wholesaler model. Note that the wholesaler can change the delivery date of the promotional storable (PS) goods, whereas the transport company can change the delivery date of the ordinary storable (OS) goods. Please see the text below the constraints for an explantion on how this affects the different constraints.

$$\sum_{r \in \mathcal{R} | A_{ir}=1} y_{irt}^{NS} = D_{it}^{NS} \qquad i \in \mathcal{N}, t \in \mathcal{T}^P \tag{18}$$

$$\sum_{r \in \mathcal{R} | A_{ir}=1} y_{irt}^{OS} = D_{it}^{OS} \qquad i \in \mathcal{N}, t \in \mathcal{T}^P \tag{19}$$

$$\sum_{t \in \mathcal{T}^P} (y_{irt}^{NS} + y_{irt}^{OS} + y_{irt}^{PS}) \leq M_1 A_{ir} \qquad i \in \mathcal{N}, r \in \mathcal{R} \tag{20}$$

$$\sum_{i \in \mathcal{N}} (y_{irt}^{NS} + y_{irt}^{OS} + y_{irt}^{PS}) \leq M_2 B_{rt} \qquad r \in \mathcal{R}, t \in \mathcal{T}^P \tag{21}$$

$$\sum_{t=\rho-E}^{\rho} w_{i\rho t} = D_{i\rho}^{PS} \qquad i \in \mathcal{N}, \rho \in \mathcal{T}^P | t > 0 \tag{22}$$

$$\sum_{r \in \mathcal{R} | A_{ir}=1} y_{irt}^{PS} - \sum_{\rho=t}^{t+E} w_{i\rho t} = 0 \qquad i \in \mathcal{N}, t \in \mathcal{T}^P | \rho \leq |\mathcal{T}^P| \tag{23}$$

$$w_{i\rho\rho} \geq (1-\alpha) D_{i\rho}^{PS} \qquad i \in \mathcal{N}, \rho \in \mathcal{T}^P \tag{24}$$

$$w_{i\rho t} \geq 0 \text{ \& integer} \qquad i \in \mathcal{N}, \rho \in \mathcal{T}^P, t \in \mathcal{T}^P \tag{25}$$

$$y_{irt}^{NS}, y_{irt}^{OS}, y_{irt}^{PS} \geq 0 \text{ \& integer} \qquad i \in \mathcal{N}, r \in \mathcal{R}, t \in \mathcal{T}^P \tag{26}$$

Constraint (18) and (19) ensure that goods that cannot change delivery date are transported in according to schedule. Note that constraint (19) for the transport company is formulated for y_{irt}^{PS} and D_{it}^{PS}. Constraint (20) ensures y_{irt} is zero if a retailer i cannot be served on route r (i.e. $A_{ir} = 0$). Correspondingly, Constraint (21) ensures that y_{irt} only takes a positive value if route r can be used (leave/depart) in time period t (i.e. $B_{rt} = 1$). Changing the delivery date of goods is handled in constraint (22)-(24). In the wholesaler model, PS pallets can be delivered earlier than scheduled by introducing $w_{i\rho t}$. Constraint (22) makes sure that all deliveries happen within the allowed time window. Furthermore, Constraint (23) connects the two decision variables y^{PS}_{irt} and $w_{i\rho t}$. The transport company can postpone the delivery of OS pallets, constraints (22) and (23) are therefore replaced with

$$\sum_{t=\rho}^{\rho+L} w_{i\rho t} = D^{OS}_{i\rho} \qquad i \in \mathcal{N}, \rho \in \mathcal{T}^P | t \leq |\mathcal{T}^P| \qquad (27)$$

$$\sum_{r \in \mathcal{R} | A_{ir}=1} y^{OS}_{irt} - \sum_{\rho=t-L}^{t} w_{i\rho t} = 0 \qquad i \in \mathcal{N}, t \in \mathcal{T}^P | \rho > 0 \qquad (28)$$

Constraint (24) defines the upper limit of cargo that can change delivery date. Note that in the transport company model, this constraint is defined for $D^{OS}_{i\rho}$. Constraints (25) and (26) impose integer requirements and non-negativity.

4 Computational Study

The optimization models are implemented in Xpress Mosel version 3.8.0 and solved with FICOXpress Optimizer version 27.01.02. All calculations have been carried out on a computer with a 3.60 GHz Intel Core i7-4790S processor and 16.0 GB RAM running Microsoft Windows 7 Enterprise operating system.

4.1 Case Data

The case data is based on real world data from a Norwegian grocery wholesaler and transport company. The area of analysis is shown in Figure 2. The transport area defines the geographical area where the retail stores are located. The wholesaler location is where all cargo is shipped from.

The analysis is carried out using daily demand data for one representative week. The main characteristics of the case are summarized in Table 1. Note that the operational routes include routes that only visit a subset of the retails stores on a tactical route.

4.2 Results

We combine the three information sharing cases (DD, WD, WW) with four different levels of flexibility: no flexibility (NF), delivery flexibility (D), route selection flexibility (R) and combined flexibility (C), i.e. both delivery and route selection flexibility. For the instance combing the weekly-weekly information sharing case with routing flexibility, we distinguish between two levels of routing flexibility,

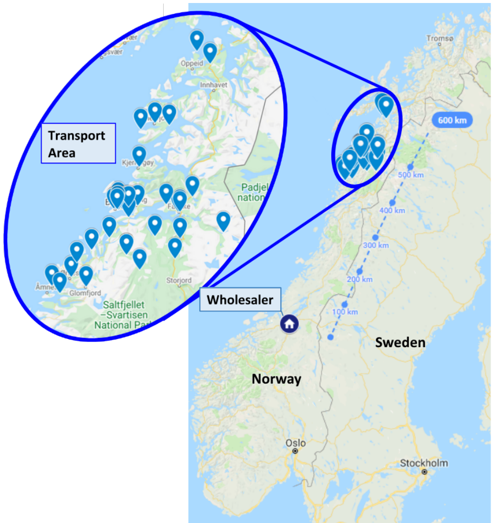


Fig. 2. Location of the wholesaler and the transport area

Table 1. Main characteristics of the case.

Description	Value
Number of retailers	39
Number of tactical routes	23
Number of daily routes/departures	[1,5]
Number of operational routes	222
Number of pallets of demand	1081
Number of PS pallets	128
Share of PS pallets that can be delivered early	0.9
Number of OS pallets	489
Share of OS pallets that can be delivered late	0.2

namely conditional, WW^{cond}, and unconditional, WW^{uncond}, routing flexibility that differ in the size of the set of available routes. For all instances, we report the relative distribution cost (in %) for the wholesaler as well as the required number of trucks and departures for the transport company. The results for the different combinations of available flexibility and information sharing cases are summarized in Table 2 and discussed in more detail below.

No flexibility Using the instances with no flexibility, we can study the isolated impact of increased information sharing between the wholesaler and the transport company. The (DD) information sharing case, where the wholesaler plans distribution for the next day and shares cargo volume and routes with the transport company on a a daily basis, represents the current planning situation and serves as a benchmark for all other problem instances.

Table 2. Results for all combinations of flexibility and information sharing cases.

Flexibility	Information sharing	Wholesaler Rel. cost	Transport Company Trucks	Transport Company Departures
NF	DD	100%	12	28
	WD	100%	12	28
	WW	100%	12	28
D	DD	100%	12	28
	WD	92.3%	11	28
	WW	92.3%	11	28
R	DD	92.8%	14	35
	WD	92.8%	14	35
	WW^{cond}	92.8%	13	36
	WW^{uncond}	92.8%	9	24
C	DD	92.8%	14	35
	WD	79.1%	16	42
	WW^{cond}	79.1%	15	40
	WW^{uncond}	79.1%	10	30

We find that all the three information sharing cases give identical results. The models in each information sharing case choose the same routes, both tactical and operational, use the same number of trucks and have the same number of departures the same day of the week. This implies that there is no or little benefit of increased information sharing alone.

Delivery Flexibility Introducing delivery flexibility allows changing the delivery date for some of the goods. PS goods can be delivered up to 7 days ahead of time in the wholesaler model, whereas OS goods can be postponed by up to 3 days in the transport company model. Exploiting delivery flexibility is only possible if the planning horizon is longer than one day. The DD instance is therefore identical to the benchmark case with no flexibility.

The wholesaler chooses the same tactical routes in all three information cases, but the cost for the wholesaler is reduced by 7.7% when the wholesaler plans increases the planning horizon for distribution planning from one day to one week. Note that the results for the wholesaler in the WD and WW information sharing cases are identical due to identical model input. The wholesaler's cost reduction is mainly due to a reduction in penalty cost for deviating from the transport volume target. Being able to change the delivery date for most of the PS pallets makes it easier for the wholesaler to achieve a constant transport volume. In fact, 52 PS pallets or approximately 75% of the goods that can be delivered earlier are scheduled for an earlier shipment.

The results from the transport company model change for each information sharing case with delivery flexibility. Most notably, the number of trucks needed to transport all cargo is reduced by one when the wholesaler extends its planning horizon to one week. In information sharing case WD, the transport company still receives transport information on a daily basis and can therefore not exploit delivery flexibility. The reduction in number of trucks can thus be attributed to the more evenly distributed transport volumes planned by the wholesaler. When delivery flexibility is enabled for the transport company in the WW information sharing case, the transport company chooses to postpone the delivery of 23 OS pallets or approximately 35% of the pallets that could have been postponed. The transport company exploits delivery flexibility less than the wholesaler, which might be due to the fact that the levelling of demand has already been done by the wholesaler. Exploiting delivery flexibility does not reduce the number of trucks or departures further. The main improvement for the transport company is due to the wholesaler exploiting delivery flexibility, rather than sharing information earlier.

Route Selection Flexibility So far, the set of available routes has been limited to the routes specific for the day of departure. When introducing route selection flexibility, we relax this assumption and make all routes in the tactical route available on all days. Note that this relaxation may violate the agreements the wholesaler has with the retail stores. For the WW information sharing case, we distinguish between two levels of route selection flexibility for the transport company: in the case conditional route selection flexibility, the transport company can chose from all routes selected by the wholesaler, whereas in the case of unconditional route selection flexibility, the transport company can chose from all routes in the tactical route plan.

When introducing route selection flexibility, the wholesaler can reduce her cost by 7.2% compared to the instances without flexibility. This is slightly worse than the solution from the delivery flexibility instances. Note that the solutions from the wholesaler model are identical for all the three information sharing cases. Extending the planning horizon does not contribute to a reduction in cost. Information sharing does not cause any benefits for the wholesaler in this instance. As the cargo volumes cannot be changed, the cost reduction in this instance is due to changing different routes. The model tries to choose the shortest route for serving the different retailers each day. Therefore, the chosen routes consist of many short routes compared to fewer and longer routes that serve more retailers in the instances with no flexibility.

With the exception of WW^{uncond}, the transport company is generally worse off in terms of number of trucks and departures than compared to the instances without route selection flexibility. This is due to the high number of short routes selected by the wholesaler, which forces the transport company to deploy more trucks in order to serve all retail stores. Sharing of information enables the transport company to reduce the number of trucks by one at the expense of an additional departure as the set of chosen routes is now available for the entire week rather than a single day. Still, even with information sharing, the results for transport company in instance WW^{cond} are worse in than in the previous instances. These results clearly highlight that a reduction in transport cost for the wholesaler does not necessarily lead to cost savings for the transport company.

With unconditional route selection flexibility, the transport company can choose any route, independent of routes chosen by the wholesaler. This increase in flexibility allows the transport company to considerably reduce the number of trucks and departures. In fact, the results are even better than ones in the previous instances. Still these results also indicate the degree of routing flexibility is more important for the transport company than information sharing.

Combined Flexibility In these instances we allow exploiting delivery flexibility and route selection flexibility at the same time. Note that delivery flexibility can only be exploiting when using a planning horizon of one week. Note that the solution for the DD information sharing case is identical to the DD solution from the route selection case, as change of delivery date is not possible. For the transport company we again distinguish between conditional and unconditional route selection flexibility in the WW information sharing case.

Compared to the instances without any flexibility, the wholesaler can reduce her transportation cost by 20.9% by extending the planning horizon to one week. Due to being able to exploit both delivery and route selection flexibility, the wholesaler is able to both even out the transported volumes per day and select the most efficient routes for serving the different retailers.

Without information sharing, the cost reduction for the wholesaler comes at the expense of the transport company, who has to deploy a total of 16 trucks in the WD information sharing case, the highest number in all of the instances. After introducing information sharing, the transport company is able to reduce the number of trucks and departures slightly under conditional route selection flexibility. Still, the numbers of trucks and departures remain higher than the instances without flexibility. Again we see that cost reductions for the wholesaler increase the costs for the transport company.

Under unconditional route flexibility, the transport company can reduce the number of trucks by 33% and the number of departures by 25% compared to the solution under conditional route flexibility. As we saw for the instances with only routing flexibility, the degree of flexibility has a larger impact on the costs of the transport company than mere information sharing.

5 Concluding Remarks

In this paper, we investigate the effect of information sharing and flexibility between a wholesaler and a transport company in the Norwegian grocery industry. The planning problems for each of the companies are formulated as individual optimization problems. The models are linked as the outcome from the wholersaler model serves as input to the transport company model. Information sharing is then modeled by controlling which information from the wholesaler model is available for the transport company model.

The different information sharing cases are combined with two different types of flexibility: delivery flexibility and route selection flexibility. Our results show clearly that information sharing alone has very limited benefits. Without flexibility to adjust decisions, the transport company cannot utilize the shared information. While delivery flexibility has a positive effect on the costs of both wholesaler and transport company, the results are less clear for route selection flexibility. The results indicate that there is a possible conflict of interest: under conditional route selection flexibility, the wholesaler's savings come at the expense of the transport company, who has to deploy more trucks. Introducing more flexibility in the planning process therefore has to consider the effect on all members of the value chain.

Different approaches for modeling the relationship between the wholesaler and the transport company, e.g. multiobjective optimization, bilevel programming or agent-based simulation, might provide additional insights, not only regarding the value of information sharing, but also for designing new, improved collaborative planning processes. The use of these approaches is subject of future research.

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