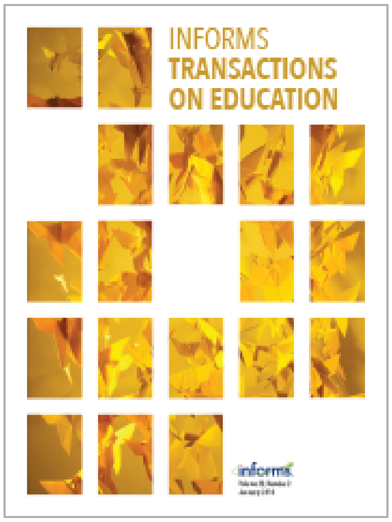

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Game

The Beer Transportation Game: How to Decarbonize Logistics by Moving Freight to Sustainable Transport Modes

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Abstract. Moving freight to sustainable transport modes is one of the most frequently mentioned suggestions to decarbonize logistics. Regrettably, even with regulation and technology developing over the past years, most of the freight volumes are still shipped via road, the least sustainable means of transport. This paper presents a beer transportation game to support logistics decarbonization via a modal shift from road to rail. In the game, student teams play the role of a logistics manager of a beer brewer and decide on the transport mode and shipment volume from the brewery to a distribution center. Their decisions are evaluated by the impact on total logistics costs and emissions. The game consists of two rounds, each with a student participation part and a lecturer debriefing part. The first round helps students understand why firms are often reluctant to shift freight from road to the low-emission transport mode (e.g., rail), and the second round encourages students to overcome the obstacles and helps them design practical approaches to alter the modal split in favor of rail transport. The game can be sealed into a 90-minute session and incorporated into any courses covering the topic of sustainable logistics or supply chain management.

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Keywords: game • decarbonization • modal shift • simulation • synchromodal transport

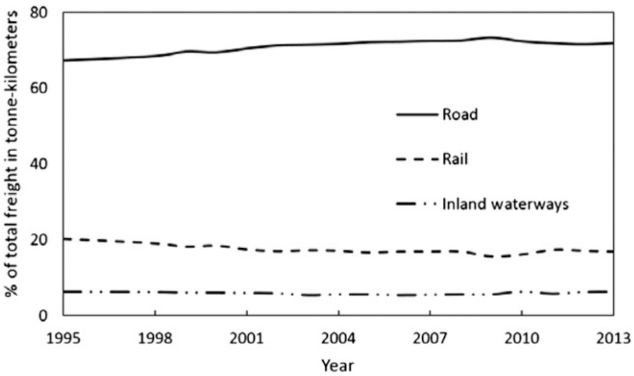
1. Introduction

In recent years, decarbonization has become a critical issue in our sustainable development. According to the Intergovernmental Panel on Climate Change (IPCC 2014), we must reduce annual greenhouse gas (GHG) emissions by 40%–70% between 2010 and 2050 so as to have a 50% chance of keeping the increase in average global temperature within 2° by 2100. Whereas all other industrial sectors are steadily reducing GHG emissions, decarbonization in transport remains difficult (European Commission 2017). It is even expected that the share of total transport emissions will still rise, making logistics one of the hardest sectors to decarbonize (Sachs et al. 2014).

By far, the most frequently mentioned freight decarbonization method submitted to the 21st session of the Conference of the Parties (COP 21) Conference (where the Paris Accord was agreed on) is a modal shift—that is, moving freight to lower-carbon transport modes (Gota 2016). According to the European Environment Agency (2013), CO_2 emissions per ton-kilometer from rail transport and inland waterway transport are about 3.5 and 5.0 times lower than those from road transport. Shifting freight from road to rail or waterway has long been seen by policymakers as the most promising way of easing the environmental problem associated with goods movement (McKinnon 2018). Over the past 50 years, there has been extensive research on altering the allocation of freight between modes (see, e.g., Bayliss and Edwards 1970, Jeffs and Hills 1990, McKinnon et al. 2015).

However, strenuous efforts to practically shift freight from road to rail over the past years have been found unsuccessful. During the last decades, the road's share of total ton-kilometers has slightly increased, and the rail's share has slightly declined (see Figure 1). Even if a growing number of schools are teaching courses on, for example, green logistics, sustainable supply chain management, and corporate social responsibility, this gap between the theoretical potential and industrial practice remains surprisingly untouched. It is especially discouraging when students or executives learn

Figure 1. The Share of Road Transport (in Ton-Kilometers) in the European Union Remains About 70% over the Last Decades, and the Shares of the Alternative, More Sustainable Transport Modes Remain Modest (European Commission 2017)



about beautiful sustainability visions and approaches in the classroom, but they later on find out that they cannot decarbonize logistics in practice by making a modal shift.

We have developed a beer transportation game to address these shortcomings and support logistics decarbonization via modal shift. In the game, student teams play the role of a logistics manager of a beer brewer and decide on the transport mode and shipment quantity from its brewery to its distribution center by evaluating the total logistics costs and emissions. The game is designed with the following pedagogical objectives:

1. Explain why it remains difficult for companies to shift freight to the more sustainable transport modes.
2. Present the latest advances in sustainable supply chain management to alter the modal split in favor of low-emission transport modes.

In Section 2, we review the related literature, and in Section 3, we introduce the beer transportation game. In Sections 3 and 4, we present the two rounds of the game that can be played during class to engage the students and enhance their learning journey. At the end of each round, we debrief the insights learned from the game and connect them to recent research. The two rounds are designed to fulfill the two aforementioned pedagogical objectives, respectively. Section 5 concludes the paper.

Although we only discuss the freight shift from road to rail transport in the game, the problem setting as well as the exercises can easily be applied to other sustainable modes such as inland waterways. The game can be used as a 90-minute module in any course covering the topic of sustainable logistics/supply chain management.

2. Literature

Our study is closely related to two streams of literature: (1) research on the use of games to teach operations management (OM) and (2) research on the use of modal shifts to decarbonize logistics.

Games have been widely used in teaching OM. The beer distribution game (widely known as the "beer game") is probably the most prominent example. As documented in Heineke and Meile (1995), it has helped students to understand the dynamics of supply chains and especially the "bullwhip" effect. Over the years, many other games, such as the dual sourcing game (Allon and Van Mieghem 2010b), the energy supply game (Belien et al. 2013), and the carbon trading game (Frommer and Robert 2017), among others, have successfully simplified sophisticated OM problems into interesting cases and exercises. They allow students to focus on the managerial insights without being confused by the complicated mathematical models. Although our game uses the popular product beer, it is not related to the popular beer game to demonstrate the bullwhip effect but is rather used in a transportation and logistics context to demonstrate the dynamics in logistics decarbonization.

The logistics industry is under high pressure to reduce carbon emissions (McKinnon 2018). Schipper et al. (2000) and IPCC (2014) have summarized decarbonization activities into four categories: (1) reducing transportation demand, (2) moving freight to sustainable transport modes, (3) improving energy efficiency, and (4) switching to green energy sources. So far the most frequently mentioned logistics decarbonization method submitted to the Paris Climate Conference is moving freight to sustainable transport modes (Gota 2016). It has "traditionally been seen by policy makers and politicians as the most promising way of easing the environmental and congestion problems associated with goods movement" (McKinnon 2015, p. 383). In this paper, we provide a game to bring logistics decarbonization to the classroom.

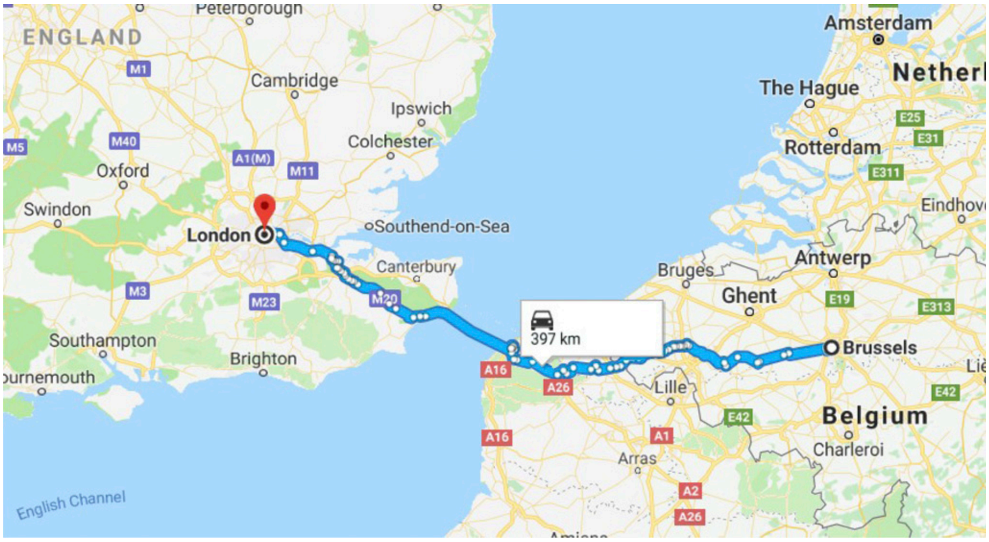
3. The Beer Transportation Game

In this section, we describe the game. A student version of this section is documented in the file BeerTransportationGame_PreReading.pdf available as supplemental material and can be distributed to the students in advance of the class (see Section 7 for more information). The lecturer may use 5 minutes to shortly introduce the game. For students without any background in supply chain management, the lecturer can spend an additional 10 minutes to review some key concepts, such as the base-stock policy to manage inventories and total logistics costs (the combination of inventory and transportation costs), although it is not mandatory.

3.1. Background

A Belgian-based brewer has a large distribution center (DC) in London to serve the UK market, which

Figure 2. On an Annual Basis, About 3,300 Full Container Loads of Beer Are Shipped from the Brewery in Brussels to the Distribution Center in London



Source. Map data @2019 GeoBasis-DE/BKG(2009), Google.

is replenished directly from the brewery in Brussels (see Figure 2). The UK market is highly competitive with uncertain customer demand that can wildly fluctuate from day to day. An unsatisfied customer order is costly because it deteriorates the brewer's reputation in customer service, and it potentially offers its market share to its competitors. The brewer therefore keeps inventory at the DC to buffer the fluctuating demand from customers.

Currently, the brewer replenishes its London DC using daily truck shipments from Brussels. The prime reason for direct trucking is the flexibility to deliver any volume as required at short notice. An order placed before 14:00 will be shipped overnight and delivered in London before 10:00 the next morning. The freight is transported and measured in full container loads (FCLs), the standard shipment unit of the industry. One truck carries exactly one FCL. It can be assumed that one FCL holds on average 10 tons (10,000 liters) of beer and 14 tons of packages (including the container itself). The payload (the total weight of a fully loaded container) of one FCL is therefore 10 + 14 = 24 tons.

The daily demand at the DC (measured in FCLs) is random, but the random distribution does not vary from day to day. Figure 3 shows the distribution of daily demand: it ranges between 3 and 18 FCLs with a mean of 10.5 and a standard deviation of 3. The DC operates from Monday to Saturday every week and hence ships about 3,300 FCLs from Brussels to London every year.

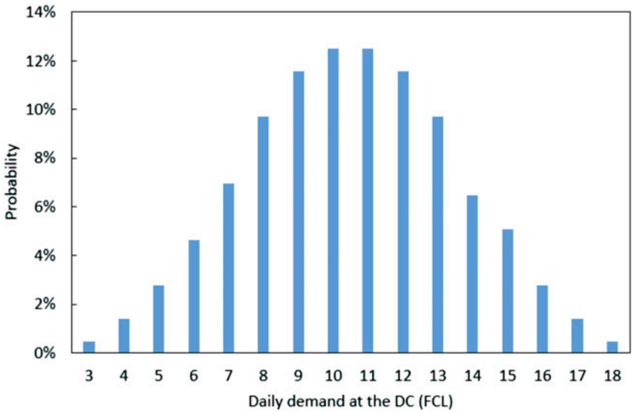
3.2. Rail: The More Sustainable Transport Mode

The brewer is aware that rail transport is more sustainable and wants to decarbonize logistics by shifting freight from road to rail. Luckily, both the brewery and the DC are located close to rail terminals. Moving freight from road to rail would require almost no additional operational effort for the brewer itself because the beer is well packed and sealed in containers, and hence the modal shift simply means transporting the same containers using rail cars instead of truck trailers.

Road transport emits on average 75 g of CO_2 per ton-kilometer (European Environment Agency 2013). The distance from Brussels to London is about 400 kilometers, so shipping one FCL emits $75 \times 400 \times 24 = 720{,}000$ g, or 0.72 ton, of CO_2. Rail transport discharges only 21 g of CO_2 per ton-kilometer (European Environment Agency 2013); hence it emits $21 \times 400 \times 24 = 201{,}600$ g, or 0.20 ton, of CO_2 to deliver the same FCL from Brussels to London. If the brewer could move all its freight (3,300 FCLs per year) from road to rail, it would save about $3{,}300 \times (0.72 - 0.2) = 1{,}716$ tons of CO_2 every year, equivalent to the annual emissions from about 800 UK households.[1]

Much to its delight, the brewer finds that rail transport is not only greener but also could be cheaper (provided some conditions are met). The average trucking cost is €1 per kilometer, so it costs €400 to transport one FCL from Brussels to London. The rail operator can offer a lower price, however, subject to a volume commitment. The management of the railfleet and the plan of train schedules are much less flexible than those of road transport (see, e.g., Newman et al. 2002, Khaled et al. 2015). The rail operator therefore requires the brewer to commit a stable volume in order to benefit from the lower price (e.g., always shipping five FCLs every time the train operates). In this way, the rail operator is able to better

Figure 3. The Probability Distribution of the Daily Demand Measured in FCLs at the London DC



manage its capacity and can offer a price of €350 per FCL shipment. In addition, the train from Brussels to London only operates on Monday, Wednesday, and Friday. Delivery times are similar to road transport: an order placed before 14:00 will be shipped overnight and delivered to London before 10:00 the next morning.

3.3. Inventory Management and Total Logistics Costs

To manage the inventory at the London DC, a so-called base-stock policy is used, which is straightforward and widely implemented in the industry. The logistics manager at the DC predefines a base-stock level—say, X—as a benchmark. At 14:00 each day, after customer demand is satisfied from the inventory in the DC, the manager records the leftover inventory—say, Y—and orders the difference, $X - Y$, from the brewery. This difference will then be transported overnight from Brussels to London. At 10:00 the next day, the manager will have X in inventory at the DC, which can be used to satisfy demand that day. Note that if the inventory exceeds the base-stock level (i.e., if $Y > X$), then no replenishment order is placed.

Obviously, the brewer wants to limit the amount of inventory held at the DC and thus does not want to set the base-stock level X too high. After all, keeping inventory is costly to the firm. The rule of thumb for nonperishable goods is that the annual inventory holding cost (which includes the cost of warehousing, the cost of capital, etc.) is 25% of the product value. Because beer has an average shelf life of one year, it is perishable, and the annual inventory write-off cost is therefore 100% of its value.[2] Assuming that the cost of the beer is €5 per liter, the daily inventory holding cost of a 10,000-liter FCL is then $5 \times 10{,}000 \times 100\%/365 =$ €136.[3] In case there is insufficient inventory in the DC to meet an unexpected large customer demand, an inventory stockout is registered with a penalty cost. This situation is especially costly because it not only induces a loss of sales but also hurts the firm's reputation in customer service. The brewer guarantees a 95% in-stock probability to its customers, which corresponds to a unit inventory stockout penalty cost of €2,584 per FCL per day.[4] Both the inventory holding and inventory stockout penalty costs are recorded to evaluate the logistics manager's performance. Table 1 summarizes the cost and emission parameters in the game.

Because the change of transport mode might impact the inventory management at the DC, the brewer should naturally evaluate the total logistics costs, including both transport and inventory costs. For simplicity reasons, we will ignore the emissions from warehousing because the storage of beer at the DC does not require cooling systems, and the corresponding emissions, compared with those from transport, are only marginal.

The logistics manager responsible for the London DC wants to evaluate whether he or she should use road or rail transport to ship its freight orders from Brussels to London. Clearly, the transport mode decision will impact both the total logistics costs and the emissions.

4. Round 1: Comparing Road and Rail Transport

4.1. Student Participation (15–20 Minutes of Class Time)

In this round, students are asked to simulate shipments using road and rail transport and then evaluate their impact on total logistics costs and emissions. Road transport is able to ship any flexible volume

Table 1. A List of Parameters Used in the Simulation

Description	Value	Unit
Average of daily demand at the DC	10.5	FCL
Standard deviation of daily demand	3	FCL
Unit inventory holding cost at the DC	136	Euros per FCL per day
Unit inventory stockout penalty cost at the DC	2,584	Euros per FCL per day
Shipping cost via road transport	400	Euros per FCL
Shipping cost via rail transport	350	Euros per FCL
Carbon emissions via road transport	0.72	Ton per FCL shipment
Carbon emissions via rail transport	0.20	Ton per FCL shipment

every day, whereas rail transport requires a fixed quantity in every delivery. In addition, it only operates on Monday, Wednesday, and Friday. This means that in order to have a stable system (where the average shipment equals the average demand), the rail shipments should equal $2 \times 10.5 = 21$ FCLs every 2 days. The daily demand is obtained by throwing three six-sided dice (which gives the probability distribution shown in Figure 3).

The simulation works as follows. First, shipments from road or rail transport are received in inventory. Then the demand is realized by throwing three dice. If the on-hand inventory is larger than demand, excessive stock will be kept to the next period with a holding cost (€136 per FCL per day); if the on-hand inventory is less than demand, a stockout will be backordered with a penalty cost (€2,584 per FCL per day). Finally, the students are asked to make a decision on the replenishment order, which will arrive at the beginning of the next day. The daily transportation costs (€400 or €350 per FCL shipped using road or rail transport, respectively), as well as the daily emissions (0.72 or 0.20 ton per FCL shipped using road or rail transport, respectively) are calculated based on the order volume and the transport mode.

Figure 4 shows the simulation table the students will receive and use to simulate the daily road shipments. After simulating the inventory and shipments, the students then calculate the corresponding costs and emissions. In the end, the students are asked to calculate the average total logistics costs per day, the average emissions per day, and the service level, measured by the number of days without a stockout. Depending on the background of the students, the lecturer could either suggest a base-stock policy with the optimal base-stock level 15 or let the students freely decide on their ordering policy.[5] A similar table is available for the simulation of rail shipments, with the notable difference that the orders placed on Monday, Wednesday, and Friday should, in principle, have a fixed quantity of 21 FCLs to have a stable system where the average supply equals the average demand. It is advised that students use the same demand numbers for both road and rail shipments in order to have a fair comparison of the costs and emissions. All simulation tables are included in the file BeerTransportationGame_GameSheet .pdf, and more information is given in Section 7.

In our game, we assume that the lead time of both road and rail transport is exactly one day (i.e., an order placed on Monday will arrive on Tuesday). In practice, however, a major issue with rail transport is delivery uncertainty, especially on long-haul moves. When freight travels a long distance on rail, the railcars must be consolidated and sorted at several rail terminals. Sometimes there are delays at these terminals, or the railcar misses the connection (to borrow a term from air transport) and has to wait for the next train to leave. One way to incorporate this uncertainty in the game is to introduce an additional coin toss: if a tail is presented, the Monday order via rail will arrive on Wednesday instead of Tuesday. This change will lead to an even higher total logistics cost of rail transport. We propose not to introduce this lead time uncertainty. It adds complexity in the debriefing of the game (see Sections 4.2 and 5.2) because of the additional randomness from the coin toss, and it complicates the Excel simulation to obtain the optimal results (see Section 5.2).

Table 2 lists an example simulation table using road transport and Table 3 for using rail transport. For example, when using rail transport (Table 3) on

Figure 4. The Simulation Table the Students Receive in the Game to Calculate the Road Shipments

Week day	Start inv (FCL)	Receive from road (FCL)	Inv before demand (FCL)	Demand (FCL)	Inv after demand (FCL)	Order via road (FCL)	Transp cost (EUR)	Inv Cost (EUR)	Total cost (EUR)	Emiss-ions (ton)
Mon	-	-	15							
Tue										
Wed										
Thu										
Fri										
Sat										

Average total transportation cost per day is: ___________________

Average total inventory cost per day is: ______________________

Average total logistics cost per day is: _________________________

Average total carbon emission per day is: ____________________

The number of days without a stock-out at the DC is: ____________

Note. A similar table is available for the simulation of rail shipments.

Table 2. An Example of the Simulation Table Describing the Shipments Using Road Transport When a Base-Stock Policy Is Adopted with a Base-Stock Level of 15

Weekday	Start inv (FCL)	Receive from road (FCL)	Inv before demand (FCL)	Demand (FCL)	Inv after demand (FCL)	Order via road (FCL)	Transp cost (€)	Inv cost (€)	Total cost (€)	Emissions (tons)
Mon	15	—	15	10	5	10	4,000	680	4,680	7.2
Tue	5	10	15	13	2	13	5,200	272	5,472	9.36
Wed	2	13	15	14	1	14	5,600	136	5,736	10.08
Thu	1	14	15	3	12	3	1,200	1,632	2,832	2.16
Fri	12	3	15	8	7	8	3,200	952	4,152	5.76
Sat	7	8	15	10	5	10	4,000	680	4,680	7.2

Thursday, the brewer starts with one unit of backorder inventory as a result of the stockout from Wednesday, and the rail transport delivers 21 units (FCL). After satisfying the backorder and the demand of that day, the brewer still has 17 units of inventory on hand. Because no train operates on that day, no order is placed, and the leftover inventory will be kept for Friday.

4.2. Debrief and Connection to Recent Research (15–20 Minutes of Class Time)

After the end of the first round, the lecturer discusses with the students the impact of both transport mode decisions. Naturally, the outcome will depend on the randomness of their dice and their preference for prioritizing emissions over costs. Nevertheless, many of them will see that despite the reduction in emissions of rail transport, the logistics costs are much higher than those of road transport, and this will be the least favorable transport mode. The lecturer could first find the supporters of road transport and ask them to explain their reasoning to their peers.

Take the simulations results in Tables 2 and 3, for example. Road transport incurs an average logistics cost of €4,592 per day, ensures a 100% service level at the DC, and emits on average 7.0 tons of CO_2 per day. Using rail transport, emissions are only 2.1 tons of CO_2 on a daily basis (a 70% emissions savings), but the logistics costs are much higher, €5,556 per day on average, and the service level is lower (i.e., 83% in-stock probability). These numbers are very sensitive to the simulated demand and therefore subject to a large variance. Because of the randomness in the dice throws, the students obtain different numerical results, and some of them might even obtain lower total logistics costs when using rail transport. The steady-state performance (when simulating for a longer period) can be obtained using the spreadsheet, available in the supplemental material as BeerTransportationGame_ExcelSimulation.xlsm, where the sheets "Road only" and "Rail only" provide long-run simulations for this round. The long-run average performance per day is given in Table 4. Because of the randomness in demand, the real value calculated in the Excel file can slightly vary.

Despite the greener image for the firm and the potential additional bonus from governments, the majority will prefer not to use rail transport. The simulation and discussions among the students represent a typical dilemma observed in industry: although rail (waterway) transport is cheaper and greener than road transport, its inflexibility in delivery quantity and frequency leads to higher total logistics costs and lower service levels. When the service level is threatened and the total logistics costs are increased, executives have to give up environmental goals. Vannieuwenhuyse et al. (2003) interviewed 500 practitioners and found that flexibility is indeed one of the most important criteria in their transport decision making. The dominance in flexibility allows road transport to receive the highest average rating in the survey despite its high cost compared with rail or inland waterway transport. A recent survey and case study by Meers et al. (2017) reassures us that the inflexibility of rail transport remains a barrier to its usage. The European Court of Auditors (2016) reports that in Europe, rail transport has failed to compete with road

Table 3. An Example of the Simulation Table Describing the Shipments Using *Rail* Transport

Weekday	Start inv (FCL)	Receive from rail (FCL)	Inv before demand (FCL)	Demand (FCL)	Inv after demand (FCL)	Order via rail (FCL)	Transp cost (€)	Inv cost (€)	Total cost (€)	Emissions (tons)
Mon	15	—	15	10	5	21	7,350	680	8,030	4.2
Tue	5	21	26	13	13	0	0	1,768	1,768	0
Wed	13	0	13	14	–1	21	7,350	2,584	9,934	4.2
Thu	–1	21	20	3	17	0	0	2,312	2,312	0
Fri	17	0	17	8	9	21	7,350	1,224	8,574	4.2
Sat	9	21	30	10	20	0	0	2,720	2,720	0

Table 4. Steady-State Performance of Road Transport with a Base-Stock Policy and Optimal Base-Stock Level of 15

Policy	Transport cost (€)	Inventory cost (€)	Total cost (€)	Emissions (tons)
100% road transport	4,219	769	4,988	7.56

Note. For rail transport, the average daily transportation cost equals €3,692, and the corresponding emissions are 2.10 tons of CO_2; inventory and logistics costs are highly unstable and may theoretically be infinitely high.

transport in the logistics service market despite financial support of €28 billion from 2007 to 2013. The road-only approach is still the mainstream baseline of most shippers.

5. Round 2: Combining Road and Rail Transport

Whereas the first round of the game demonstrates why firms are often reluctant to use the more sustainable rail transport, this round encourages students to propose feasible solutions that reduce total logistics costs and emissions at the same time.

The core of the solutions is a simultaneous use of both transport modes so that the advantages of both modes can be captured. In other words, the brewer could apply, instead of an either-or selection between road and rail transport, a both-and use of them. Note that some of the students might have already suggested this in the first round.

5.1. Student Participation (20–25 Minutes of Class Time)

The students can now replenish a part of the demand using rail transport and a part using road transport. The rail transport again delivers a fixed quantity on Monday, Wednesday, and Friday. However, in this case, only a portion of the average demand (21 FCLs every 2 days) is to be allocated to rail, so the fixed allocation to rail can now be fewer than 21 FCLs per shipment, but it should remain stable over time. The remaining volumes can be shipped using road transport.

The students are now asked to design their own strategy to combine both rail and road transport; that is, they decide the fixed volume via rail transport every other day and the variable volume via road transport every day. They receive an empty simulation table similar to that in Figure 4 (all simulation tables are available for download; see Section 7). The sequence of events remains the same as in the first round.

Because the students are working with different random numbers, their decisions and simulations will again vary. Here we present one of the most commonly proposed approaches: ship the lower bound of the random demand of 2 days (i.e., six FCLs) using rail transport and the rest via road transport using a base-stock policy with base-stock level of 15. This approach ensures that rail transport never delivers in excess of the actual demand and therefore will not adversely impact the inventory at the DC. Table 5 provides the simulation results of this policy (we have used the same demand pattern as in round 1 to facilitate the comparison with only road or only rail transport).

The average total logistics cost per day using this policy is for this example €4,442, the average emissions per period is 5.4 tons of CO_2, and the service level remains 100%. Compared with the road-only case in Table 2, this leads to 3% total logistics costs saving and 23% emissions savings without reducing the service level at the DC.

Students may propose different ways to split volumes between the two transport modes and obtain different results. We think anybody who can obtain a carbon reduction ratio no lower than 23%, without increasing total logistics costs or reducing the service level, deserves to be the winner of the game.

Table 5. An Example of the Simulation Table, with the Possibility to Replenish Both Using Road *and* Rail Transport, Where Six FCLs (the Lower Bound of Demand) Are Shipped Every Other Day Using Rail Transport and a Base-Stock Policy with a Base-Stock Level of 15 Is Used for Road Transport

Weekday	Start inv (FCL)	Receive from road (FCL)	Receive from rail (FCL)	Inv before demand (FCL)	Demand (FCL)	Inv after demand (FCL)	Order via road (FCL)	Order via rail (FCL)	Transp cost (€)	Inv cost (€)	Total cost (€)	Emissions (tons)
Mon	15	—	—	15	10	5	4	6	3,700	680	4,380	4.08
Tue	5	4	6	15	13	2	13	0	5,200	272	5,472	9.36
Wed	2	13	0	15	14	1	8	6	5,300	136	5,436	6.96
Thu	1	8	6	15	3	12	3	0	1,200	1,632	2,832	2.16
Fri	12	3	0	15	8	7	2	6	2,900	952	3,852	2.64
Sat	7	2	6	15	10	5	10	0	4,000	680	4,680	7.2

5.2. Debriefing and Connection to Recent Research (20–25 Minutes of Class Time)

Similar to the debriefing in round 1, the lecturer could first ask a few student groups to show their results and ask them about the experience they have gained and then summarize the insights. Note that because student groups all work with different random demands, it is not meaningful to compare the results among them. Instead, they should only compare their own results with the first rounds of the game. In most cases, the total logistics costs as well as the emissions will be reduced when using a combination of road and rail transport. The extent to which costs and emissions are reduced depends on the effective modal split between road and rail transport.

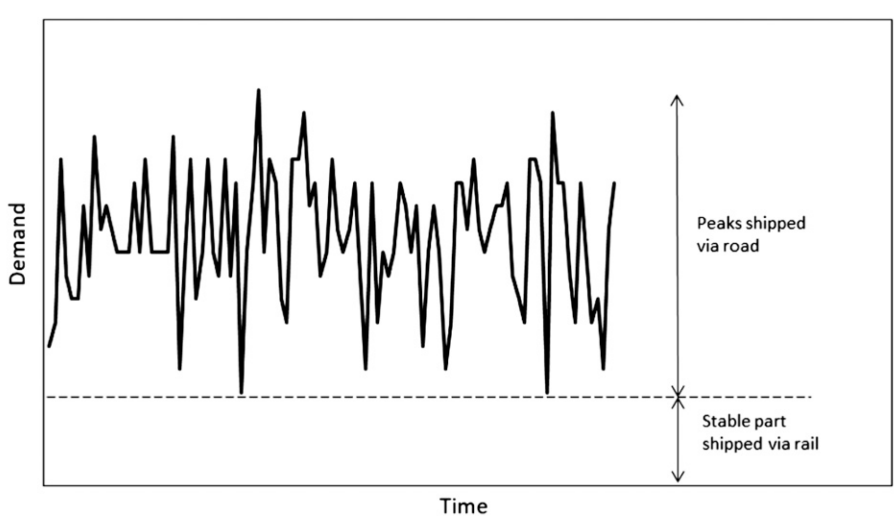
A smart combination of both road and rail transport serving for the aggregated demand is denoted as "synchromodal transport" (or "synchromodality"), which is a novel approach that has recently emerged to decarbonize logistics (Verweij 2011). Whereas the use of rail transport increases the economic and environmental performance of the logistics system, the use of road transport secures the responsiveness to the volatile demand. The simultaneous use of both transport modes allows the firm to capture the classical cost–service trade-off of logistic systems and decarbonize logistics without trading off other logistics metrics.

Groothedde et al. (2005) suggest this practice of shipping the stable demand via rail transport and the volatile peaks via road transport (see Figure 5). Behdani et al. (2016) describe the simultaneous use of both transport modes as the "horizontal integration" of freight transport planning, as a contrast to "vertical integration," where the different transport modes are sequentially used in a freight movement (e.g., a truck–rail–truck intermodal movement). They regard it as a distinct feature of synchromodality. Synchronized logistics systems are expected to be an essential approach to decarbonize logistics (Alliance for Logistics Innovation through Collaboration in Europe 2014).

However, in case of highly volatile demand, the stable part of the demand can be rather small. In the approach simulated in Table 5, only 6/21 = 29% of the total volume is shifted from road to rail transport, and at most 23% carbon emissions can be saved. Some of the students might have proposed to shift more freight from road to rail to further decarbonize logistics. If not, the lecturer could initiate this suggestion. Increasing the share of rail transport implies that the horizontal bar in Figure 5 is raised upward. As a result, shipping costs and emissions will be lower, but more inventory will be held at the DC because the fixed rail shipments may exceed the required shipment quantities. In other words, reduced shipping costs and emissions are traded off against increased inventory costs. Unfortunately, the optimal solution of this problem (i.e., the optimal allocation to rail shipments) is complex and cannot be solved easily. The main reason is that the mathematical structure of the problem is similar to that of the dual sourcing problem, in which the inventory controls are intractable (see, e.g., Allon and Van Mieghem 2010a, Dong et al. 2018a).

To understand the underlying dynamics of this system, the lecturer can use our macro-enabled spreadsheet (the file BeerTransportationGame_Excel Simulation.xlsm; see Section 7 for more information), which allows the students to investigate the transport–inventory trade-off to move more freight from road to rail transport without understanding the detailed mathematics behind it. Figure 6 shows how the different types of costs change as a higher portion of the freight is shipped using rail transport. A similar plot can be found in Dong et al. (2018b). The solid curve

Figure 5. An Approach to Combine Both Road and Rail Transport: to Ship the Stable Part of the Demand via Rail and the Peaks via Road



represents the total logistics costs per period, and the two dotted curves represent the inventory and transport costs. When more freight is shipped using rail transport, the transport costs decrease linearly. The inventory costs, by contrast, first increase very moderately and suddenly surge when all freight is shipped using rail transport. This indicates that the inflexibility of rail transport indeed increases inventory, but this impact is only significant when almost all freight is shifted from road to rail. In that case, it does not have sufficient flexibility in its shipments, and a large amount of inventory is accumulated at the DC to buffer demand uncertainties.

Point A in Figure 6 represents the current baseline situation with road transport only, and point B represents the practice explained in Section 5.1 with the lower bound of demand—that is, about 29% of the total volume shifted to rail transport (6 FCLs per rail shipment). The total logistics costs are minimized at point C, indicating that the brewer is able to reduce its total logistics costs by shifting about 52% of total freight to rail transport (i.e., 11 FCLs in our game). By applying this approach and moving from point A to point C, the logistics manager can reduce its total logistics costs by about 4% and carbon emissions by about 38%, which nearly doubles the carbon savings obtained from the approach described in Section 5.1. The latter approach is represented by point B, with about 3% cost savings and 20% emissions savings in the long run. Noteworthy is that at points A, B, and C, the same service level is obtained with the same base-stock control at the DC. The average cost performance of points B and C is given in Table 6 (the cost performance of point A was given in Table 4). Because of the randomness of demand, the numbers calculated in the Excel file may vary slightly.

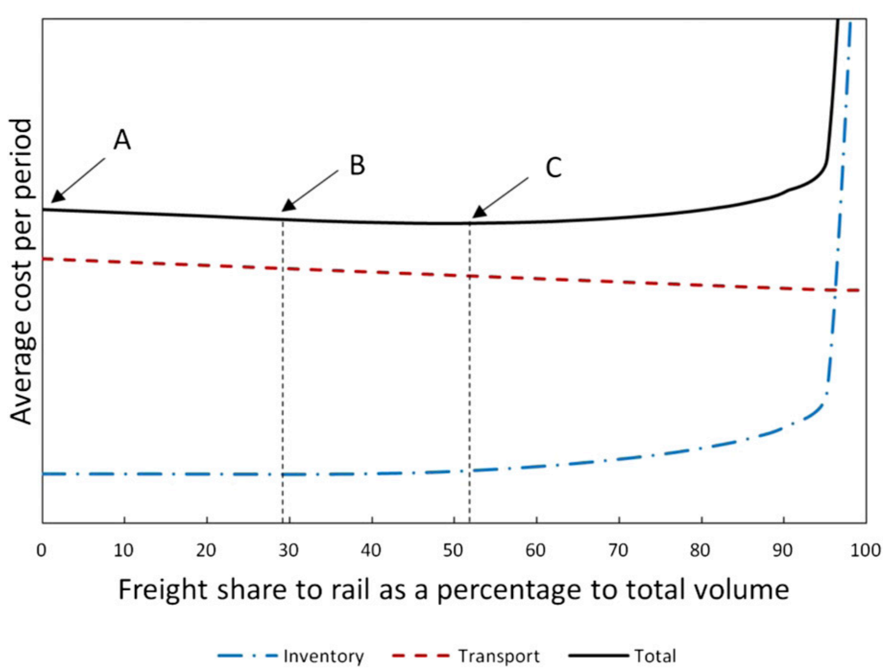
The surprisingly high ratio of freight that can be shifted to rail transport obtained at point C is not a coincidence. Allon and Van Mieghem (2010a) and Dong et al. (2018a) analyze the characteristics of the model and demonstrate, with approximate analytic expressions, that the optimal solution will be obtained when a large modal shift to rail transport is realized. This approach slightly increases the inventory costs compared with using only road transport; however, the transport cost savings offset the extra inventory costs, and thus it reduces the total logistics costs. This approach allows the brewer to shift about 50% of the total freight from road to rail and therefore decarbonize its logistics.

6. Summary and Classroom Experience

6.1. Summary of the Key Takeaways

In this paper, we present a beer transportation game designed to teach logistics decarbonization via a modal shift from road transport to low-emission transport modes such as rail. The main takeaway of the game is to demonstrate the adverse impact of the more sustainable transport modes on supply chain metrics,

Figure 6. When the Brewer Shifts More Freight from Road to Rail, It Incurs Higher Inventory Costs but Lower Transport Costs



Notes. Point A represents the current situation (only road shipments), point B represents the practice of shipping the lower bound of demand using rail transport (6 FCLs per shipment), and point C represents the point where total logistics costs are minimized (11 FCLs per rail shipment). When 100% of the freight is shipped using rail, the inventory and logistics costs go to infinity.

Table 6. The Steady-State Performance of the Daily Performance When Combining Both Rail and Road Transport into a Synchromodal Policy

Policy	Transport cost (€)	Inventory cost (€)	Total cost (€)	Emissions (tons)
Point B: 29% rail transport	4,069	772	4,841	6.00
Point C: 52% rail transport	3,944	824	4,768	4.73

such as inventory and service level, and inspire students to simultaneously use different transport modes to optimize modal shift decisions in a wider supply chain realm. The game is accompanied by a spreadsheet analysis to debrief with the latest state-of-the-art advancements to modal shift research.

6.2. Classroom Experience

So far the game has been played with an international group of master's students with diverse backgrounds (half of them study business/management, and the rest are mainly in engineering), as well as with doctoral students majoring in logistics.

Students are suggested to work in groups of two to five. If there are too many groups, it is difficult to manage; if there are too few groups, the randomized results (because of the dice throws) might not be generalized for conclusions. We recommend to play the game with about 5–10 groups.

The students have played the game with great interest and enthusiasm; they enjoyed the active participation and the sense of realism of the game. They were especially surprised to realize via their own simulations that although rail transport is cheaper and greener, it will often not be used because of the adverse impact on other supply chain metrics such as total logistics costs and service level. Even the senior doctoral students majoring in logistics experienced this "wow" effect and appreciated that aspect of the game. In the second round of the game, the students regard the combination of rail *and* road as a novel "thinking out of the box" approach, which motivated them to design their own logistics decarbonization strategies. It enhanced their insight into the trade-off between transport and inventory, especially in combination with Figure 6 showing how transport, inventory, and total logistics costs change when shifting freight from road to rail transport. It is also our experience that students from Nordic countries might have a stronger preference for low-carbon emissions and are willing to trade higher logistics costs for lower emissions. Nevertheless, in general, students will acknowledge that in most companies, costs will be prioritized over emissions.

From the lecturer's point of view, the game is easy to explain, and it highlights an important practical problem of logistics decarbonization. It only requires a few dice and printed game sheets to play the game (nowadays, even several versions of digital dice are available online). Although the game describes a typical logistics/supply chain management problem, it is easy to play with students without any relevant background in logistics/supply chain management. In this case, however, it may be advised to review some key concepts such as total logistics costs and base-stock control at the beginning of the game.

7. Download Information

Two pdf files and one Excel file are available as supplemental material. The pdf file BeerTransportationGame_PreReading.pdf describes the game and can be distributed to the students prior to the class. The pdf file BeerTransportationGame_GameSheet.pdf lists the simulation tables the students will work on during the game. The macro-enabled Excel file BeerTransportationGame_ExcelSimulation.xlsm consists of four sheets. The "Road only" sheet simulates the costs and emissions when only the road transport is used, and the sheet "Rail only" simulates the results when only rail transport is used. The sheet "Synchromodal lower bound method" allows a simultaneous use of both transport modes, with rail transport shipping the lower bound of the volatile demand, and the final sheet, "Synchromodal optimal," incorporates a macro that calculates the optimal modal split between road and rail transport by a mouse click. All four sheets share the same set of parameters.

Endnotes

[1] According to the World Energy Council (2014), a household in the United Kingdom emits on average 2.12 tons of CO_2 per year.

[2] The lecturer can, in principle, freely choose which of both to use for his or her game because this is a parameter that can easily be changed. We will adopt the write-off cost in the remainder of the game as the inventory cost.

[3] In case annual inventory holding costs are only 25% of the product value, the daily inventory holding cost would be 34.

[4] The in-stock probability is given by the critical newsvendor fractile: (unit holding cost)/(unit holding cost + unit stock-out penalty cost). Interested students can read any standard textbook covering inventory fundamentals for more information.

[5] Students with a background in inventory management may derive the optimal base-stock policy themselves. The optimal base stock = average lead time demand + $z \times \sqrt{\text{lead time}} \times$ standard deviation demand = $10.5 + 1.64 \times \sqrt{1} \times 3 \approx 15$.

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