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Sharing Breakdown Information in Supply Chain Systems: An Agent-Based Modelling Approach

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Abstract

Sharing the different types of information among *Supply Chain* (*SC*) agents has often been cited as a way to reduce the SC risks. In this paper, an agent-based representation of the *Beer Game Model* (*BGM*) is used to demonstrate how disruptions, occurring to the factory of a SC, can negatively affect its overall performance, and how sharing the factory disruption information can effectively help blocking the evolution of risk in the SC and improve its performance. The BGM is extended in this research to include two factories. The concept of *Reverse Information Sharing* (*RIS*) is introduced as a mechanism for sharing the breakdown information. The results show a significant reduction in the cost of the SC and each of its agents due to the RIS. In addition, the analysis shows that the RIS significance is getting larger with the increase of the disruption frequency.

Keywords: Reverse Information Sharing, Beer Game, Agent-Based Modeling, Supply Chain Risk.

1. Introduction

Information Sharing (*IS*) has emerged as one of the most essential practices in improving the performance of *Supply Chains* (*SCs*). Downstream IS or the demand-side information has been focused on in the literature (e.g., the sales information or inventory status at the sale points). This represents, however, a single type of the entire information flow in a SC (see, for example, Lee, So, & Tang 2000; Chen, Drezner, Ryan, & Levi 2000; Xu, Dong, & Evers 2001). The upstream IS or supply-side information forms another type of IS that has been also proved crucial for the SC management (Li & Gao 2008). This type of IS includes sharing aspects, such as, *Lead-Time* (*LT*), new-product introduction, and plant operations. In contrast to the downstream IS, the upstream IS has received less attention (Chen 2003). A recent trend stresses its importance as a complementary approach to sharing the downstream information.

The new trend of sharing the upstream information, referred to here as *Reverse Information Sharing* (*RIS*), is driven by two factors. The first factor considers the availability of the technologies required for applying this type of IS. This includes the *Enterprise Resource Planning* (*ERP*) systems, *Customer Relationship Management* (*CRM*) systems, and *Business-To-Business* (*B2B*) exchanges. The second factor is the increased customer awareness of the importance of IS and, as a consequence, the increased customer pressure for sharing the information including the upstream information (Jain & Moinzadeh, 2005).

Although the RIS appears to be widely applicable now, its full impact on the SC has not been fully studied. Most of the existing models about upstream information investigate sharing the LT or supply availability information. For example, Chen & Yu 2005 quantify the value of sharing the LT information in a single-location inventory system. They assume a model with a single supplier that knows exactly the LT for every replenishment order. The study shows that the cost savings from sharing the LT information can be significant. Jain & Moinzadeh 2005 study a one-manufacturer one-retailer inventory system in which the retailer is allowed to access the inventory information of the manufacturer. The numerical investigations lead to insights about the value of this type of information to the retailer and demonstrate how RIS might increase the manufacturer’s profits. The model also leads to insights that provide guidance to managers on when and how to apply RIS.

Lee, Padmanabhan, & Whang 1997 discuss the possibility of preventing the bullwhip effect through sharing the manufacturer inventory information with the downstream agents. Croson & Donohue 2005 examine the effectiveness of giving the SC agents access to the downstream inventory information for alleviating the bullwhip effect. They find that sharing only upstream information offers no significant performance improvement. Rather than sharing the LT or supply availability information, Li & Gao 2008 analyze the effect of sharing the upstream information of the introduction of a new product. They contrast the case in which the manufacturer does not share the upstream information about the new-product with the retailer and the case in which the manufacturer shares the information. They demonstrate that information sharing improves the performance of both supply chain entities. They find also that when demand variability increases, information sharing adds more benefits to the supply chain.

This paper introduces RIS as a promising mechanism for SC risk management. The more you know, and know early enough, the less unprepared you may be about the unforeseen developments in the SC.

Risk is broadly defined as a chance of danger, damage, loss, injury, or any other undesired consequences (Harlanda, Brenchleyb, & Walkera, 2003). Juttner 2005 classifies SC risks into *Supply Risks* (*SRs*) and *Demand Risks* (*DRs*). While the SRs influence the downstream agents, the DRs influence the upstream agents. Kuijpers 2009 defines *Supply Chain Disruption Risk Management* (*SCDRM*) as the process of systematically identifying, analyzing, and dealing with disruption risks in SCs, through coordination or collaboration among the SC agents, to decrease SC vulnerability and increase SC resilience, so as to ensure profitability and continuity for the whole SC. SCDRM thus focuses on reducing the chance or the impact of risk with an ultimate goal of ensuring the SC continuity (For a review about SCDRM see: Harlanda, Brenchleyb, & Walkera, 2003; Chopra & Sodhi 2004; Tang 2006).

When a major disruption occurs, many SCs tend to break down and take a long time to recover. Sheffi & Jr 2005 present a profile for the company response to disruption characterized by eight phases (see Figure 1). First, in the preparation phase, a company can foresee and prepare for disruption and hence minimize its negative effects. However, in some cases, there is a little or no warning before the disruption event by which the supplier is shutdown. The first response should then aim at controlling the situation and preventing further damage. The full impact of some disruptions can be felt immediately, while for others, the full impact can take time. During the time between the disruptive event and the full impact, performance usually starts to deteriorate. Once the full impact hits, performance often drops precipitously. Recovery preparations typically start in parallel with the first response and sometimes even prior to the disruption, if it has been anticipated. The recovery phase might involve qualifying other suppliers and redirecting suppliers' resources (For a comparison between the single supplier approach and multiple supplier approach see Pochard, 2003; Yu, Zeng, & Zhao 2009). To get back to normal operation levels, many companies make up for lost production by running at higher than normal utilization. It typically takes time to recover from disruption, but if customer relationships are damaged, the impact can be especially long-lasting and difficult to recover from.

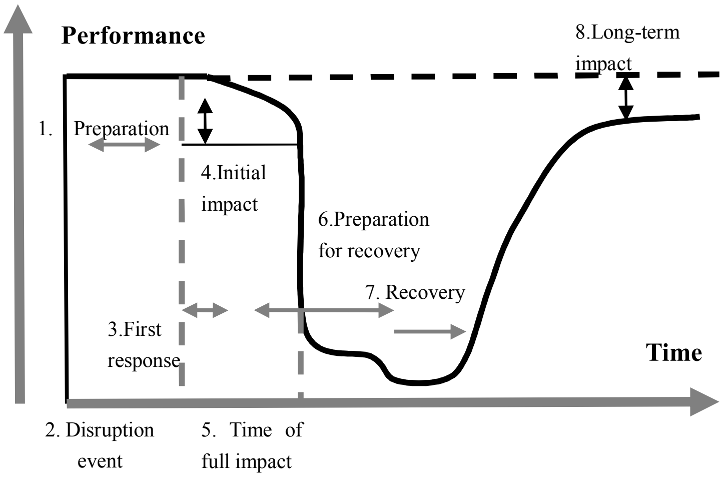

Figure 1: The Disruption Profile (Sheffi & Jr 2005)

Given the increased importance of risk management for today's complex SC systems, this paper contributes to the literature by analyzing the effect of sharing the upstream disruption information, as a kind of RIS, on alleviating the disruption problems. In this context, disruptions are defined as major breakdowns (BDs) in the production or distribution agents in a SC. This might include events, such as, fire, machine breakdown, or unexpected shortage in capacity that creates a bottleneck, quality problems, or natural disasters (Handfield 2007).

In this research, an *Agent Based Model* (*ABM*) of a typical *Beer Game* (*BG*) is introduced to study the value of sharing the disruption information among the SC agents. BG is a widely-known SC simulation model that is used for studying the features of information and physical flows distribution in supply networks (see Simchi-Levi & Zhao 2003; Klimov & Merkuryev 2006). The ABM is a relatively new simulation approach. It is used to represent the dynamics of the interacting agents in the SC systems for its flexibility in representing heterogeneous, interacting agents in an open environment (Charoo, Santos, & Reis 2008).

In the simulation, a factory sudden disruption, that hinders its ability to fulfill new orders, is introduced. The results of two scenarios for the sudden disruption are investigated and compared. In Scenario 1, the disruption information is not shared. In Scenario 2, the factory shares the disruption information with the distributor.

This paper is organized as follows. In Section 2, the experimental model is discussed. Section 3 presents the results. Finally, Section 4 concludes the results and discusses the possible extensions to this research.

2. The Experimental Model

The BG is simulated as a multi-agent system to investigate the significance of the RIS on the SC performance in the abnormal cases. The model is designed to allow the investigation from the viewpoint of the SC system as a whole and from the viewpoint of each of its agents.

The model is developed using VB.Net. Each agent type is represented as a class with a set of attributes, e.g. the inventory level of the agent, and a set of predefined behavioral rules, for guiding the decision making process of the agents of this type. The behavioral rules include actions to be taken in the different situations including how to handle customer demand, when to replenish the inventory, and how to decide the level of the next order. The following subsections include a detailed description of the model.

2.1 The Agents

Five main classes of agents are defined representing the customer, the retailer, the wholesaler, the distributor, and the factory. From each class a number of agents can be defined. For example, two factories are defined in the model.

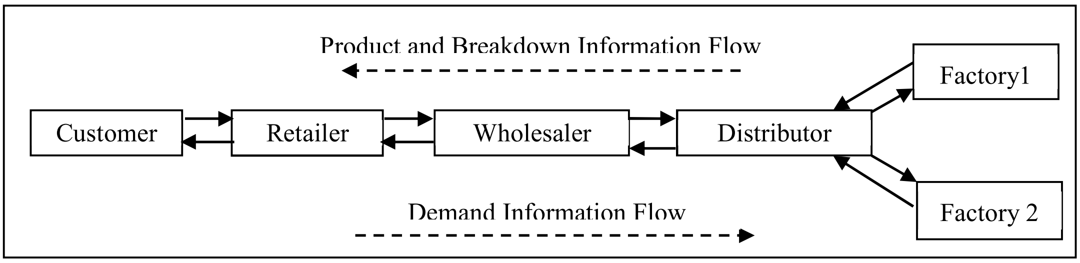

Figure 2: The Beer Game Model With Two Factories

Each agent in the model represents a SC node that places orders to its supplier to fulfill its clients' demand. Customers are modeled as a collective end-node agent that places orders to the retailer according to a pre-defined consumption pattern. The BGM assumes that the retailer is the only agent that knows the real market demand. The demand information is consecutively transmitted, starting from the retailer, up to the upstream agents in a form of orders. At the other end of the chain, the factory agent is placed and assumed to be ready to immediately fulfil any order. This is because the BG model assumes that the factory has an unlimited production capacity with unlimited supply of the raw material.

This research introduces factory breakdown (BD) as a source of SC disruption and thoroughly examines the effect of sharing the BD information on alleviating the problem at the level of the entire SC as well as at the level of each of its agents.

2.2 The Agents' Behaviour

Each agent has an objective of minimizing its inventory, and hence cost, through optimizing the quantity to order. Although each agent is self-interested and free to decide for itself when and how much to order, the goal of the entire SC should still be satisfying the end-customers; otherwise, all the agents will lose. Figure 3 shows the interaction frame between any two agents in a SC.

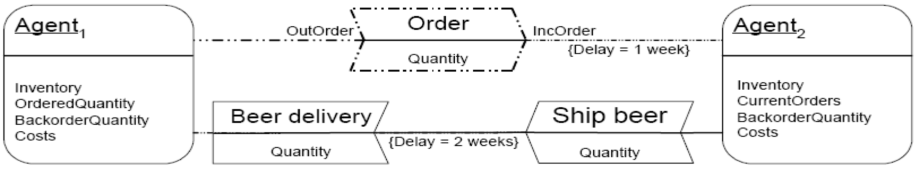

Figure 3: The Interaction Frame between Two Agents in a SC (Jeroen, Florin, & Gerd 2004)

In their repetitive interaction, each agent sends an order to and receives a shipment from its upstream agent. The shipment received in the current cycle fulfills the orders from the previous cycles depending on the LT. Each agent adds the shipment received to its inventory and the quantity ordered from it to its backorder, if any, to determine its total outstanding demand. The agent fulfils the total demand if its inventory permits, i.e., the inventory is equal to or greater than the total demand. The agent then ships the quantity demanded, deducts it from the inventory, and sets the backorder quantity to zero. If the inventory is insufficient, the entire inventory is shipped and the remaining, unfulfilled demand is added to the backorder. Finally, each agent decides the amount to order from its supplier and then calculates its cost. This cycle is repeated long enough to study the system behavior. The typical time granularity for the BGM is a "week" and the typical number of cycles is 50 weeks.

When a sudden BD occurs at the main factory (F1), the factory halts its production and hence is not capable of sending any shipments to its downstream agents. The distributor is the first agent that realizes the problem then the effect of the factory stoppage is felt all over the SC. Because of the existence of more than one supplier, the distributor switches to another factory, F2. However, the earlier the BD problem is realized, the less the damage to the SC and each of its agents is expected.

3. Experiments and Results

As in a typical BG, the market demand is deterministic and set at the level of eight units/week. As we are not interested in studying the bullwhip effect, the demand is fixed during the simulation. All experiments run for 50 cycles (weeks). The inventory/backorder cost ratio is assumed 0.5. The ordering LT is assumed one week, the shipping LT is two weeks, and hence the LT is 3 weeks. In contrast to typical BG simulations, the initial inventory of all agents is set to zero instead of four units. This is to neutralize the inventory effect and focus on studying the significance of the RIS on the backorder accumulation.

A set of preliminary experiments is conducted to check the influence of the BD parameters on the results. Afterwards, two scenarios are examined. In Scenario 1, the factory does not notify the distributor with the BD problem. This case is referred to as *No Reverse Information Sharing* (*NRIS*) case. In Scenario 2, the factory notifies the distributor with the BD immediately after it occurs. This is referred to as the *Reverse Information Sharing* (*RIS*) case. The results of Scenario 1 and Scenario 2 are then contrasted.

3.1 Preliminary Investigations

This section is devoted to study the sensitivity of the model, the SC average cost in particular, to the new BD parameters: the *Breakdown Week* (*BDW*), *Duration* (*BDD*), and frequency or *Repetition* (*BDR*).

3.1.1 Influence of Breakdown Time

Under a fixed breakdown duration (BDD=5) occurring only once (BDR=1), the BDW intuitively shows no influence on the results as long as the BD occurs long enough before the end of the simulation. In particular, the BDW needs to be assumed before week 40 to allow the order and shipment cycle to complete and hence report the results after the system is completely stabilized. This result is applicable in both cases of NRIS and RIS.

3.1.2 Influence of Breakdown Duration

This experiment investigates the influence of the BDD on the overall SC cost. A single BD is assumed to occur at week 25. Ten different BDD are examined: BDD $\in\{1, 2,\ldots, 10\}$. The results show no influence of the BDD on the SC average cost in both cases of NRIS and RIS. This is actually for two reasons. First, the distributor is assumed to shift to another factory directly after it realizes, in the case of NRIS, or get informed, in the case of RIS, about the problem. Second, the model only considers the inventory and the backorder in the cost function. It has to be stated that considering more complicated cost functions, including factors, such as, losing customers or opportunity cost, is expected to lead to different results (see further research below).

3.1.3 Influence of Breakdown Repetition

This experiment investigates the influence of the BDR on the overall SC cost. Assuming that the BDD is 4 weeks, Figure 4 illustrates the SC average cost when the BD is repeated up to five times in the two cases of NRIS and RIS. The BDs are planned not to intersect as two intersected BDs can be simply considered as a single long BD.

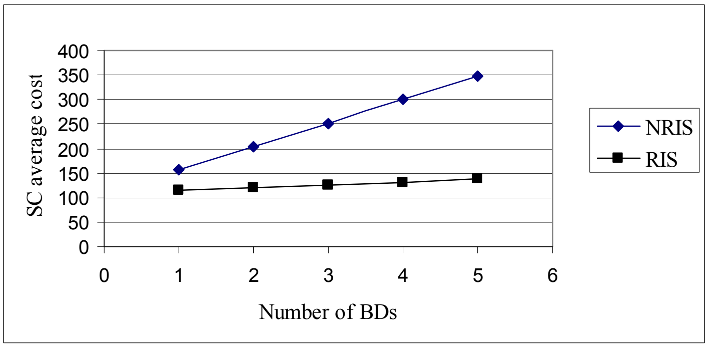

Figure 4: SC Average Cost under Different Number of BDs in Both Cases of NRIS and RIS

The results indicate a linear relationship between the number of BDs and the SC average cost in both cases of NRIS and RIS. This is because each BD has a fixed cost; however, the cost is different in the case of NRIS from the case of RIS as the slopes of the lines indicate. This result is discussed further below.

3.1.4 Conclusion of the Preliminary Experiments

Both of the breakdown time and duration have shown no influence on the results. Accordingly, in the experiments below, a breakdown with a fixed week and duration is used. In contrast, the breakdown repetition has a positive linear relationship with the SC cost. However, the analysis of a single breakdown is applicable to many breakdowns; that is, the results of a single breakdown can be scaled up for any number of breakdowns. Therefore, the analysis below focuses on a single breakdown; however, the results of a number of breakdowns are reported and discussed at the end.

3.2 Scenario 1: The Case of NRIS

According to this scenario, a sudden BD occurs at the main factory (F1), but F1 does not notify the distributor with the problem. Therefore, the distributor only realizes that a problem has occurred only when no shipment is received. At this moment, having known nothing about the problem, the distributor decides to switch to the second factory (F2).

Since the LT is assumed to be three weeks, there will be a three-week delay until the distributor receives the shipment from F2. During this period, the backorder accumulates for the SC agents. The problem starts to solve only when the distributor receives the shipment from F2 and then passes it to the wholesaler, from which to the retailer and finally to the customer.

Figure 5 and Figure 6 illustrate, respectively, the agents placed order and backorder in the case of a single sudden BD. The BD occurring at F1 starts at week 30 and lasts for 5 weeks; this is denoted by BD (30, 5).

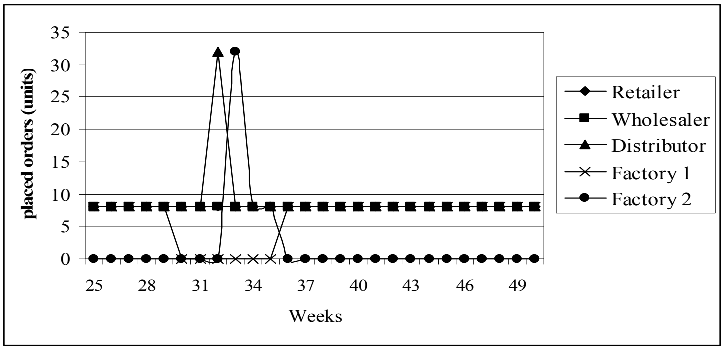

Figure 5: Agents Placed Orders with a Factory BD, BD (30, 5), in the Case of NRIS

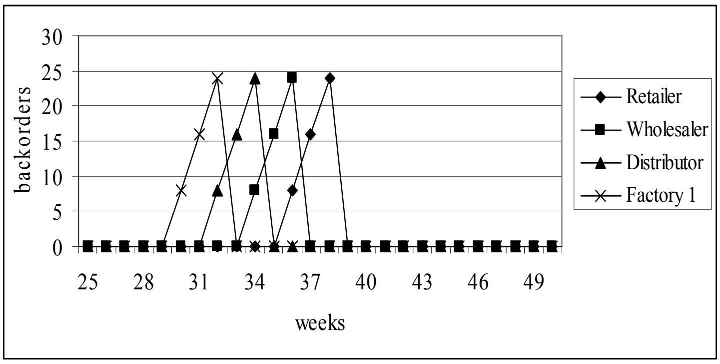

Figure 6: Agents Backorders with a Factory BD, BD (30, 5), in the Case of NRIS

Table 1 includes detailed information about the distributor main variables since the BD starts at week 30 and until the problem is resolved at week 38. As shown in the table, although the sudden BD in F1 occurs at week 30, the distributor continues to receive shipments from it at week 30 and 31. These are actually the shipments sent at week 28 and week 29 due to the shipping LT. At week 32, the distributor receives no shipment from F1 and only at this moment, it realizes that some problem has occurred to the factory.

Having known nothing about the nature of the problem, the distributor decides to shift to F2. Since the weekly demand is eight units and the LT is three weeks, the distributor needs to order (weekly demand × (1+LT) = 32) from F2. This amount is used to cover the backorder that is expected to accumulate at weeks 32, 33, and 34, during which the distributor does not receive any shipments. Backorder accumulation of the SC agents is illustrated in Figure 6. In this scenario, the distributor is assumed to shift back to its original supplier, F1, immediately after the end of the breakdown, week 35 in this case. This is actually assumed to enable a systematic study for a repetitive BD at F1 as discussed above.

Week	**Backorder**	**Demand**	**Incoming Shipment**		**Outgoing Shipment**	**Placed Order**	
			From F1	**From F2**		**To F1**	**To F2**
30	0	8	8	-	8	8	-
31	0	8	8	-	8	8	-
32	8	8	-	-	-	-	32
33	16	16	-	-	-	-	8
34	24	24	-	-	-	-	8
35	0	32	-	32	32	8	-
36	0	8	-	8	8	8	-
37	0	8	-	8	8	8	-
38	0	8	8	-	8	8	-

Table 1: Distributor Data with a Factory BD, BD (30, 5), in the Case of NRIS

3.3 Scenario 2: The Case of RIS

In this scenario, F1 decides to share the sudden BD information with the distributor immediately after it occurs. This enables the distributor to directly, at the stoppage week, start contact with F2 and hence minimize the delay period from three weeks, representing the LT, as in the case of NRIS, to only one week, representing the ordering LT. Figure 7 and Figure 8 illustrate, respectively, the agents placed order and backorder when a sudden BD (30, 5) occurs at F1 with the RIS applied.

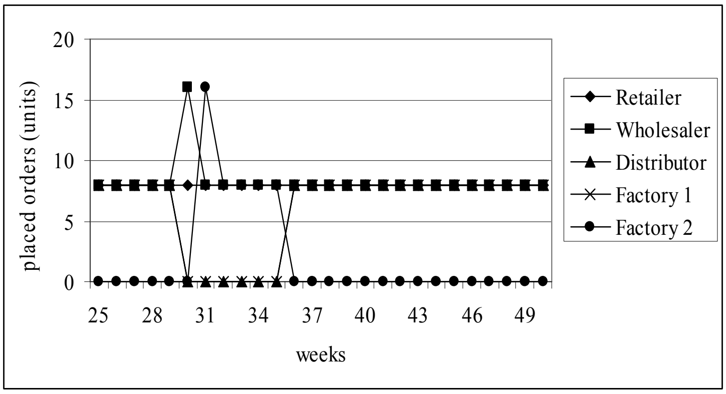

Figure 7: Agents Placed Orders with Factory BD, BD (30, 5), in the Case of RIS

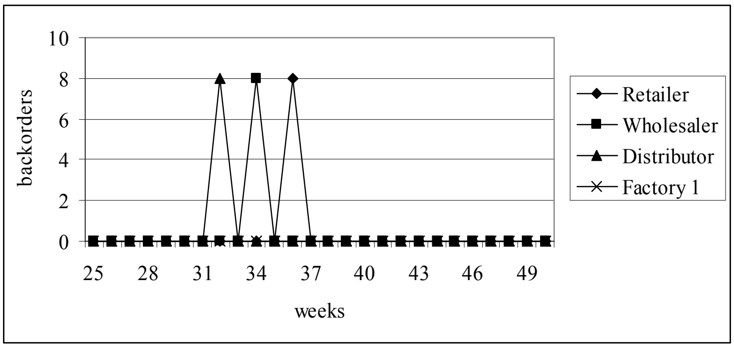

Figure 8: Agents Backorders with Factory BD, BD (30, 5), in the Case of RIS

Table 2 includes detailed information about the distributor main variables since the BD starts at week 30 and until the problem is resolved at week 38. F1 informs the distributor that a BD occurs at week 30 and will last for 5 weeks. At week 30, the distributor places an order of 16 units, for covering the backorder and the order of week 32 during which the distributor receives no shipment from either factory. The distributor keeps directing its order to F2 until F1 gets back to work. At week 35, the distributor sends its order to F1, to be received at week 38. During this period, the distributor continues receiving shipments from F2 as shown in the table.

Week	Backorder	Demand	Incoming Shipment		Outgoing Shipment	Placed Order	
			From F1	From F2		To F1	To F2
30	0	8	8	-	8	-	16
31	0	8	8	-	8	-	8
32	8	8	-	-	-	-	8
33	0	16	-	16	16	-	8
34	0	8	-	8	8	-	8
35	0	8	-	8	8	8	-
36	0	8	-	8	8	8	-
37	0	8	-	8	8	8	-
38	0	8	8	-	8	8	-

Table 2: Distributor Data with a Factory BD, BD (30, 5), in the Case of RIS

3.4 Contrasting the Results

Table 3 contrasts the cost of each agent, under a single BD (30, 5), in the case of NRIS with the case of RIS. The SC average cost in both cases is also reported. The results show that all the SC agents get benefited from the RIS with an obvious preference to the upstream agents. The factory, in particular, is the most benefited agent from sharing the information. The whole SC average cost is reduced by 26.92% (see Figure 9).

	Average Cost		
SC Agent	**NRIS**	**RIS**	**Reduction in Cost**
Retailer	228	188	17.54%
Wholesaler	204	164	19.61%
Distributor	144	104	27.78%
Factory 1	48	0	100%
SC	156	114	26.92%

Table 3: Agents Costs with Factory BD, BD (30, 5), in Both Cases of NRIS and RIS

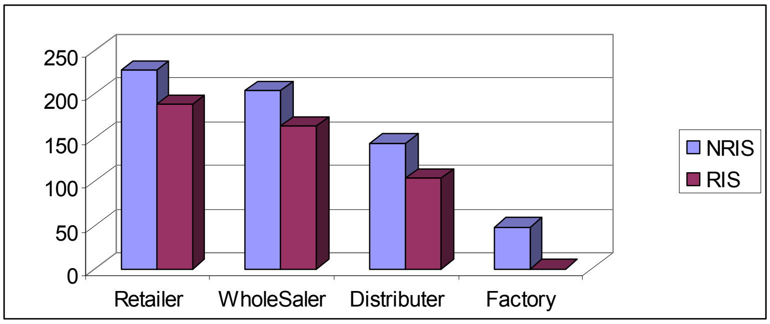

Figure 9: Agents Costs with Factory BD, BD (30, 5), in Both Cases of NRIS and RIS

As discussed above, the number of breakdowns has a positive linear relationship with the SC cost. Table 4 contrasts the SC average cost in the NRIS case with the RIS case under different BD repetitions: BDR $\in \{1, 2, 3, 4, \text{and } 5\}$. The results show that the more the repetition of the BD is, the larger the significance of the RIS on the SC cost reduction appears to be. For example, in contrast to the case of a single breakdown in which the RIS achieves about 26% reduction in cost, with 5 breakdowns the RIS reduces the cost with about 60%.

	SC Average Cost		
BD Repetition	**NRIS**	**RIS**	**% Reduction Due to RIS**
1	156	114	26.92
2	204	120	41.18
3	252	126	50
4	300	132	56
5	348	138	60.34

Table 4: SC Average Cost under Different Number of BDs in Both Cases of NRIS and RIS

4. Conclusion and Further Research

The results above provide us with valuable insights into the RIS mechanism. First, the results stress the significance of the RIS in alleviating a factory disruption problem. In addition, the analysis shows that the RIS significance is getting larger with the increase of the problem frequency. Despite the possible confidentiality of the disruption problem to the factory agent, the results show that the factory will be the most benefited agent, in terms of the cost reduction, if the disruption piece of information is shared. All that the factory needs to reveal about the problem is announcing its existence and transmitting the length of the closing period to the distributor. Despite it is not the problem initiator, the distributor is the agent that needs to take an action to save the SC by shifting to another factory. Although the shifting cost is not included in the model, the distributor has to pay it whether the information is shared or not, but the sooner is better. The distributor is also shown as the second most benefited agent from sharing the information. RIS also helps in reducing the cost of the retailer and the wholesaler. In case the shifting cost is higher than the distributor can afford, the results indicate that all the SC agents might contribute in some way in the shifting cost as long as they all get benefited.

A number of cases are to be considered in our further research. First, considering more complicated cost functions, including factors, such as, losing customers or opportunity cost, is underway. This type of functions is expected to lead to different results. Second, a reliability factor will be included in the model to reflect the level of trust in the factories based on their breakdown frequencies and whether the factory shares the information with the downstream agents. In addition, sharing planned shutdown information is to be investigated. In this type of disruption, the factory knows that it will be closed long enough before the shutdown. The factory assumptions of the unlimited production capacity and the unlimited supply of the raw material are relaxed to investigate the behavior of the SC and the backorder accumulation due to the different types of shutdown.

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