Risk Sharing in Joint Product Development – Lessons from 787 Dreamliner

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Reconciling an empirical study[1] of 787 delays with an economic analysis of financial incentives, we reveal a subtle incentive trap in the risk sharing partnership that encouraged Boeing and the suppliers to delay deliberately despite the disastrous effect. We suggest a remedy to avoid the trap and greatly alleviate delays for joint development programs of this kind.

1. Introduction

The Boeing 787 Dreamliner was the fastest-selling plane ever in the commercial aviation industry,[2] but its development was a nightmare. In this article we analyse Boeing's traumatic experience, discover what really happened, identify the root causes, and offer ways to avoid similar disasters in the future. We believe that such lessons can provide valuable insights for companies around the world to ensure successes in joint product development.

Our conclusion is simple. A majority of 787 development delays may be deliberate and thus could have been avoided! The root cause of these delays is a subtle incentive trap in the risk sharing partnership induced by the "wrong" risk shared among Boeing and the suppliers. This led the firms into a "prisoner's dilemma" wherein delays were in their best interests even while they were driving themselves into a disaster. We reconcile an empirical study of the actual events with an economic analysis of financial incentives, and reveal the rationale behind many seemingly irrational behaviours that delayed the 787 program. We show that properly distinguishing different types of risk and sharing only the "right" risk can help aligning the interests of partners and thus significantly reduce or completely avoid such deliberate delays.

787, the Dreamliner, was believed to be the most advanced commercial aircraft ever built and the most efficient to operate, due to its unprecedented use of the lightweight composite materials.

Background

1.1 The 787 Development Program. 787, the Dreamliner, was believed to be the most advanced commercial aircraft ever built and the most efficient to operate, due to its unprecedented use of the lightweight composite materials.[3] The Dreamliner is also unprecedented in the scale of development outsourcing – 65% of the development work is outsourced to more than 100 suppliers from 12 countries.[4] Exhibit 1 (see next page) provides details on tier-1 suppliers.

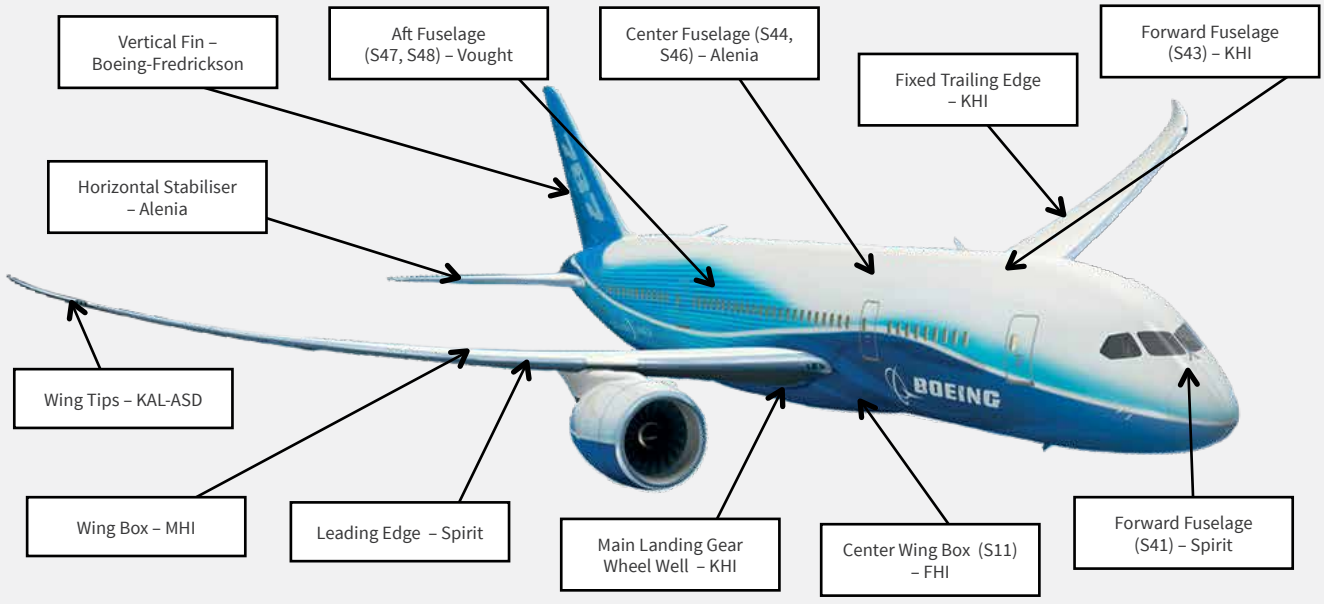
Tier 1 suppliers design and fabricate 11 major subassemblies, Boeing integrates and assembles. Specifically, Boeing defines the parts and interfaces, but leaves the detailed design to suppliers who can optimise within each work package, and must work with each other on the interfaces. In case of disputes, Boeing serves as a referee to assist the suppliers.[5] Development outsourcing provides Boeing significant benefits:

1. **Market expansion**. Outsourcing workload to other countries helps to secure sales of the airplane to these countries before product launch. Development outsourcing is instrumental in making the Dreamliner the fastest-selling plane.
2. **Technology**. Development sourcing enables Boeing to utilise the best in-class expertise and knowledge worldwide, and thus reduces the technological risk.

787 does not stand alone in workload outsourcing. Other noticeable examples include Airbus 380 and the Global Hawk; statistics shows that, on average, about 50% of the revenue of Raytheon was paid to the suppliers.[6]

1.2 The Risk Sharing Partnership. Development outsourcing is not without challenges. Unlike the model of one-firm-does-all, different

EXHIBIT 1. The 787 tier-1 suppliers (KHI – Kawasaki Heavy Industries, FHI – Fuji Heavy Industries, MHI – Mitsubishi Heavy Industries, KAL-ASD – Korean Airlines - Aerospace Division)



tasks that constitute a project are performed by different firms who rely on each other to control their cost and schedule. Thus, a critical issue is incentive alignment because firms may optimise for their own benefit rather than that of the project.

Development projects typically require iterations. Thus to align incentives, Boeing must ensure that no supplier can cash out before the project completes. This requirement rules out the fixed price contracts (as in subcontracting) where the suppliers are paid upon job completion, and thus can walk away from future iterations. Furthermore, Boeing must motivate the suppliers to work hard and cost efficiently. This requirement rules out the time-material contracts (as in consulting), which may encourage suppliers to work slowly and inflate their cost.

To manage development outsourcing, Boeing came up with an ingenious idea – the risk-sharing partnership, which makes the suppliers the stakeholders of the 787 program.[7] Specifically, Boeing asked the risk-sharing partners to bear the up-front non-recurring R&D investment for their work, and wait until the plane is certified and delivered to get paid. So the suppliers share the risk of program delays. The payment follows a pre-negotiated price per unit, and so the more planes Boeing sells, the more money each supplier makes. To compensate the suppliers for taking the risk, Boeing assigned them the intellectual property rights of their work, and so the suppliers have the assurance from Boeing that they will not be replaced down the road.

The risk-sharing partnership promised tremendous benefits to Boeing: first, it reduces substantially Boeing's upfront investment.[8] Second, it reduces Boeing's exposure to delay risks because Boeing only bears the cost of its own investment if the project is ever delayed. Finally, suppliers may be motivated to work efficiently and hard because they spend their own money and share the loss of delays.

Development outsourcing plus risk-sharing (dubbed "Build-to-Performance") seems a wonderful idea. Boeing strongly believed that risk sharing provides the right incentives and so left the selection and control of subtier suppliers to its risk sharing partners.[9]

1.3 The 787 Disaster. In reality, 787 development was a disaster – the first flight was delayed by 26 months and the first delivery was delayed by 40 months with a cost overrun of at least $11 billion by the first delivery,[10] including write-offs due to defects (~$2.5 billion), excessive R&D costs (~$3.5 billion), customer contract penalty (~$5 Billion). It was the worst delay in the commercial aviation industry (see Exhibit 2 next page, upper left).

Naturally, people asked, what caused the delay? How could it have been avoided? Three conjectures were proposed:

1. **Union strikes**.[12] If we look at the actual events, union strikes only delayed 3 out of the 40 months total. So the unions had an impact but not substantial.

Exhibit 2. Comparing Boeing 777, Airbus 380 and Boeing 787[11]

	Official launch date	Planned 1st delivery date	Planned program duration (months)	Actual 1st delivery date	Actual program duration (months)	Delay of the 1st delivery (months)	Total Development cost (all firms involved)
777	1/1990	5/1995	***64***	5/1995	***64***	***0***	***~$6-7 billion***
380	12/2000	2/2006	***62***	10/2007	***82***	***20***	***~$13 billion***
787	1/2003	5/2008	***64***	9/2011	***104***	***40***	***≥ $20 billion***

Exhibit 3. 787 major delays

#	Time anounced	Duration	Causes given	Responsible firms	Explanations
1	10/ 2007	7 months on the 1st flight	Parts shortage (e.g., fasteners)	Alcoa Vought Alenia Spirit GA Honey-well etc.	Issues with production capacity & scale economies
			Defects. Unfinished work from suppliers		Lack of testing & quality assurance equipment & personnel, workers lack of training and FAA compliance, had to use student inspectors
			Design issues		Vought had no engineering dept. when selected
			Missing documentation		Suppliers had to rush to meet the schedule
			Flight control software		The supplier underestimated the time
2	1/ 2008	3 months on the 1st flight	Unfinished work from the suppliers	Vought Alenia GA Boeing	Suppliers: the same
			Slow assembly progress at Boeing		Boeing: "we underestimated how long it takes to do someone else's work"
3	4/ 2008	6 months on the 1st flight	Same as above	Same as above	Same as above
4	12/ 2008	6 months on the 1st flight	Wrongly installed fasteners at Boeing FAL	Boeing	Poorly written instructions by Boeing engineers confused and misled its workforce
5	6/ 2009	Indefinitely on the 1st flight	Defects at wing-body joint	Boeing Fuji Mitsubishi	Structural flaw in design and engineering
6	8/ 2010	3 months on the 1st delivery	Uncontained engine failure & availability issue	Boeing Rolls Royce	Unknown
7	12/ 2010	Indefinitely on the 1st delivery	An on-board electrical fire	Hamilton Sundstrand	Foreign debris in electric cabinets, and more

2. **Technical issues**.[13] It is true that the composite materials have never been applied so extensively to a plane of this size; but such materials were not new as they were applied to the 737 and 777 programs. A thorough examination of the actual events shows that only 3 out of a total 7 major delays are probably caused by unexpected technical issues.
3. **Too much outsourcing**. This is the most popular conjecture.[14] However, it is yet supported by practical evidence and also too vague to provide actionable guidelines.

2. The Empirical Study: What Happened?

In January 2003, Boeing started to design and sell a new plane, later named the 787 Dreamliner. The original plan is to have the suppliers complete and deliver all subsystems by June 2007. Boeing integrate and assemble the plane in June-July 2007, test the 1st flight in August 2007, and make the 1st delivery in May 2008.[15] In May 2007, all subsystems of the first Dreamliner, LN 1, were delivered to the final assembly plant with the following status:[16]

- After fuselage (by Vought) structure is 16% complete, systems integration 0%.
- The nose-and-cockpit session and the forward fuselage (by Spirit & Kawasaki) sagged out of shape in transit due to incomplete frame and floor beam installation.
- Redesign for interfaces and body joints made by different suppliers.
- Due to a fastener shortage issue, temporary fasteners were used for the first few 787s. However, the replacement of these temporary fasteners is hampered by a lack of documentation.

LN 1 status marks the start of 7 major delays, summarised in Exhibit 3 (see Exhibit 3 at lower left) by duration, direct causes, responsible firms and their explanations.[17]

Out of the 7 major delays, the last 3 may be caused by technical issues, the first 4 of them are caused by some "irrational" behaviours of Boeing and its suppliers, as summarised at the right.[18]

These "irrational behaviours" represent human errors and mismanagement so obvious and trivial that Boeing and its suppliers must already know. Thus, the question to ask here is not how to correct these errors, but, knowing it was wrong, why did Boeing and suppliers still do it?!

Exhibit 4. The "irrational" behaviours of Boeing and the suppliers

"Irrational" behaviours	Why irrational?
Boeing selected Vought to design and manufacture the world's 1st all-composite aft-fuselage, but Vought had no engineering department when selected	Boeing knew Vought well as a longtime customer.[19] How could Boeing select a firm with limited engineering capability to design and fabricate one of the most technical and novel parts?
General Aeronautica used low-wage, trained-on-the-job workers with no previous aerospace experience to assemble fuselage sections, and didn't train them for FAA compliance until the job is past-due	As a joint venture between two experienced aircraft manufacturers (Alenia and Vought), it is impossible for GA to not know the very basics – training its workforce for the FAA compliance.
Alcoa quoted a lead time of 60 weeks for fasteners, citing issues of capacity & scale economies, contributing to the first delay. In response, Boeing aggregated fastener procurement, ensuring favourable pricing	• No matter how sophisticated the fasteners are, they won't take 60 weeks to make. Alcoa was bargaining for a better deal • Rather than giving Alcoa a better deal to reduce the lead time, Boeing pressed Alcoa further on pricing, which prolonged the lead time.
Tier-2 suppliers lack of Q/A equipment and personnel to do testing at component and subsystem levels. Tier-1 suppliers deferred testing to FAL	What kind of engineering and manufacturing firms will design and fabricate a new part without testing it?
Vought (Charleston, SC) had to use novice student inspectors because it had problems attracting competent technicians	Using interns to assure the quality of the world's 1st all-composite aft-fuselage? No wonder why numerous defects have gone unnoticed.
Production records on suppliers' work were found incomplete or lost in transfer resulting in a loss of configuration control	As experienced aircraft manufacturers, it is impossible for them to forget production records or get them lost in transit, against common sense.
Poorly written instructions led to the embarrassing wrongly installed fasteners at Boeing	It is such a careless mistake for Boeing, a company holding such a high reputation in engineering, to mess up instructions for installing fasteners.

3. The Economic Analysis: The Incentive Trap

To see the financial incentives that led the firms into these errors, we first classify costs for development projects:[20]

- **Direct costs:** expenses for research, engineering and testing, workforce and training, equipment, materials, and transportation. One can reduce the direct costs by delaying the task.
- **Indirect costs:** including overheads (utilities, facilities, and benefit), capital costs, contract penalty, and order cancellations. Indirect costs increase in project duration.

Under the risk-sharing partnership, each firm invests on its task and gets paid when the whole project is completed. Thus, if a firm delays its task, it saves its direct cost but everyone suffers a higher indirect cost due to the resulting project delay. Firms completed their tasks on time are penalised, and the firm delayed is not fully responsible for the damage it caused. Intuitively, if one firm can benefit from a delay and have others share the damage, the firm may delay. This subtle incentive trap is related to the "moral hazard" issue in the economics literature[21] and can be deadly for development projects.

Under the risk-sharing partnership, each firm invests on its task and gets paid when the whole project is completed.

A simple example (see appendix), resembling Dreamliner's workload distribution, manifests this incentive issue and reveals a deep insight: the risk sharing partnership can put the firms into a Prisoners' Dilemma – although keeping the planned duration benefits the entire project, it can be in each firm's best interest to delay. In summary, although risk sharing may seem to motivate partners to work efficient and hard, it actually provides a strong incentive for them to delay deliberately so that they can save their own cost at the expenses of others.

4. Reconciliation: What Caused The Delays?

We now reconcile the analysis in §3 with the events in §2, to reveal the rationale behind the "irrational" behaviours. We first discover what the suppliers really said behind their explanations for the delays (see Exhibit 5 next page, upper left).

The reconciliation implies that the delays occurred not because the suppliers weren't able to do their jobs well but because they just didn't want or care enough to do it well. These suppliers were delaying their work as much as possible and doing it in the cheapest possible way!

Let's now discover what Boeing really said behind its explanations for the delays (see Exhibit 6 next page, lower left).

The reconciliation indicates that Boeing was really just concerned about its own cost and risk rather than the delays of the 787 program.

These "irrational" behaviours are

Exhibit 5. The rationale of suppliers

Suppliers' "irrational" behaviours (explanations for delays)	*What did the suppliers really say?*	Reasoning
• **Lack of testing and Q/A equipment and personnel** • **Used low-wage, train-on-the-job workers to assemble fuselages** • **Inability to attract competent technicians, have to use novice student inspectors**	*I don't want to spend money on it*	• If you paid the salary of an intern, you only get interns. • If the suppliers really cared about their work, they shouldn't have saved money from necessary equipment and qualified personnel.
• **Workers lack of training & FAA compliance** • **Incomplete documentation or lost in transit**	*I don't care much to manage it well*	The FAA compliance training only takes a couple of days.[22] Even the documentation was lost in transit, how careless they were!
• **Vought waited till 5/2006 to build the plant (job assigned 11/2003, due 5/2007)[23]**	*I wish I could delay it more*	Vought took 2 ½ years to build the plant, only left itself 1 year to build the part. Recall that the part is only 16% complete (§2).
• **Alcoa quoted a 60-week lead time for fasteners, citing capacity issues & scale economies.**	*I only care about my thousand $ setup cost but your million $ plane*	Alcoa was reluctant to speed up production without obtaining a better volume and price deal from Boeing.[24]

Exhibit 6. The rationale of Boeing

Boeing's "irrational" behaviours (explanations for delays)	*What did Boeing really say?*	Reasoning
Alcoa quoted a 60-week lead time for fasteners, citing issues of capacity & scale economies, contributing to the first delay. In response, Boeing consolidated its fastener procurement, directly negotiated with suppliers, for favourable pricing	*I care more about the prices than the delays of the fasteners*	If Boeing cared more about the delays than the prices, it should have encouraged the fastener suppliers to reduce lead time by making a better volume and/or price commitment, rather than discouraged them by pressing them more on pricing.
Boeing selected Vought who had no engineering department to develop the world's 1st all-composite aft-fuselage.	*I need someone to share the cost and risk more than getting the project done on-time*	Had Boeing not known Vought's engineering capability (as a long time partner) and the damage of hiring a firm with limited technical capability? Negative, but the need of sharing risk dictates.
"We underestimated how long it takes to do someone else's work" – slow progress at FAL to fix the traveled work.	• *We estimated delays, but underestimated them.* • *We don't have to hurry up to save suppliers' money*	Boeing was expecting delays but nothing so bad. Why should Boeing work hard to catch up the schedule so that the suppliers can reap most of the benefit?[25]
Embarrassing wrongly installed fasteners – poorly written doc. by Boeing Engr. misled its workforce	*I don't care much to manage it well*	If Boeing were more committed, such low-level mistakes should have been avoided.

detrimental to the 787 program, but they can be rational to each individual firm, because doing so can save its direct costs, and have the damage, the extra indirect cost, shared by other firms. Thus, knowing the "irrational" behaviours were wrong for the project, Boeing and the suppliers still did it because it was in their best interests.

5. The Solution: How Could It Have Been Avoided?

The trend of development outsourcing is irreversible because product development today is an undertaking often too complex, expensive and risky for one firm. Thus, to avoid similar disasters in the future, we must find ways to make the risk sharing partnership work!

5.1 Controllable vs. Uncontrollable Delays. A frequently raised question for the Dreamliner program is why Boeing did not penalise its partners for their delays? To answer this question, we must understand that there are two types of risk in development projects: the risk of uncontrollable delays and the risk of controllable delays. (see Exhibit 7 next page)

Boeing did not penalise the suppliers for their delays because Boeing doesn't like to pay penalty to the suppliers for its own delays. This is the essence of the risk-sharing partnership: if the delay is caused by unpredictable and unavoidable events such as natural disasters and unexpected technical challenges (the uncontrollable delays), no individual firm should be held responsible. Sharing the risk of such delays is not only fair but also effective as it allows the firms to diversify the risk in product development.

The risk sharing partnership of 787, however, does not distinguish the types of risk but also force the firms to share the risk of controllable delays, which is not fair because a firm should not be held responsible for others' mistakes. More importantly, sharing the risk of controllable delays encourages such delays (i.e., the incentive trap in §3) and thus leads to suboptimal project performance. Thus, neither penalising nor sharing all types of delay risk is fair or effective.

5.2 The Fair Sharing Partnership. To align the incentives of firms in joint development projects, we propose a new partnership, namely, "fair sharing", which allows the firms to share the risk of uncontrollable delays but assumes each firm the

full responsibility for its own controllable delays. Specifically, upon a delay, the firms shall first identify its type. In case of an uncontrollable delay, the damage is shared in the same way as under the risk sharing partnership. But in case of a controllable delay, the firm responsible shall pay not only for its own damage but also for the damages of other firms caused by the delay. In this way, the firms can share the risk of uncontrollable delays and achieve diversification; meanwhile, they can eliminate the incentive trap and align their interests with that of the project.

We must point out that the fair sharing partnership isn't a panacea as its effectiveness relies on the firms' capability to distinguish the types of risk, which is not always possible especially in projects involving creative activities and substantial technical challenges. When such a project is delayed, it can be hard to tell whether the firms involved haven't tried their best or they tried but failed. Fortunately, the fair sharing partnership applies to complex projects with minor or moderate technical advances, such as extension, upgrading, or new combinations of existing technologies. These projects represent a vast majority of the development programs in many industries.

5.3 How Could It Have Been Avoided? Had Boeing utilised the fair sharing partnership, the first four delays could have been avoided or at least mitigated because both Boeing and the suppliers would have taken a much greater responsibility for their delays and thus been much more committed than they were under the risk-sharing partnership. That said, there may still be delays, like the last three, but mostly due to unforeseeable technical challenges.

On the implementation side, because the fair-sharing partnership requires a much greater responsibility than the risk-sharing partnership, some suppliers may be reluctant to sign on. If Boeing must use a supplier even if it declines the responsibility, then knowing the supplier's incentive to delay, Boeing should closely control and monitor the supplier to prevent potential "irrational" behaviours.

In reality, Boeing fought the delays by first tightening its control of the suppliers (tiers 1, 2, and 3) around the globe.[26] Boeing built a high-tech operations center in a factory in 2008 to monitor the suppliers in real time to ensure that the 787 components and modules are tested right away at the original manufacturers before shipped out to the next level of integration. Second, Boeing acquired Vought's interest in Global Aeronautica in June 2008, and bought Vought's 787 operations in South Carolina entirely in July 2009.[27] After these acquisitions, Boeing's share of the delay damages increased considerably, and it tightened up its internal control. Consequently, there are no more embarrassing mistakes since then, and the last three major delays are largely due to unexpected technical issues.

Exhibit 7. The types of delay risk

The uncontrollable delays	The controllable delays
• Technical challenges • Natural disasters • Union strikes	• Careless lapse • Errors due to mismanagement • Firms' strategic behaviours
Unpredictable and unavoidable	Predictable & avoidable by extra effort & commitment

6. Conclusion

The trend of outsourcing is irreversible in product development especially for large and complex engineering systems. Although risk sharing may seem a wonderful idea to manage development outsourcing, it may encourage deliberate delays and cost overruns if the "wrong" risk (the risk of controllable delays) is shared. The 787 program manifests this subtle but deadly incentive trap that management should avoid in joint product development. Our research suggests that properly distinguishing different types of risk in project execution and sharing only the "right" risk (the risk of uncontrollable delays) can help firms better align the incentives, and so they may continue development outsourcing without sacrificing project performance.

Appendix

In this example, we have two sequential tasks, A and B, for which, the planned durations are 9 and 5 weeks. We can delay each task by one week, and save $900 (for A) and $1200 (for B) in the direct costs. If the project takes longer than the planned duration, 14 weeks, it suffers an extra indirect cost of $1600 per week.

We must point out that the fair sharing partnership isn't a panacea as its effectiveness relies on the firms' capability to distinguish the types of risk, which is not always possible especially in projects involving creative activities and substantial technical challenges.

In the "one-firm-does-all" model, the firm would not delay any task because the extra indirect cost of the project upon delay exceeds the savings in the direct costs of all tasks. In the outsourcing and risk-sharing model, let's assume that firm A does task A, firm B does task B, and upon each week of the project delay, firm A pays an extra indirect cost of $750 and firm B pays $850 (the total indirect cost is still $1600/week). To find out what firms A and B would do in their best interests, we consider four scenarios:

1. (**Win-Lose**) If firm A delays but firm B keeps its task duration, then the project is delayed by one week. A saves $900 but loses $750 with a net gain of $150, while B suffers a net loss of $850.
2. (**Lose-Win**) If firm A keeps its task duration but firm B delays, then firm A suffers a net loss of $750, while firm B saves $1200 but loses $850 with a net gain of $350.
3. (**Lose-Lose**) if both firms A and B delay, then the project is delayed by two weeks, where firm A incurs a net loss of $600 (= 2x$750 - $900) while firm B suffers a net loss of $500 (=2x$850 - $ 1200).
4. (**Win-Win**) Firms A and B can negotiate a mutually beneficial deal, in which, both keep their task durations and thus lose nothing.

Exhibit 8. A simple example: the scenarios and pay-offs of firms A and B

Firm A \ Firm B	Delay	Keep
Keep	A: −$750 B: $350 (Lose-Win)	A: $0 B: $0 (Win-Win)
Delay	A: −$600 B: −$500 (Lose-Lose)	A: $150 B: −$850 (Win-Lose)

Exhibit 8 summarises the scenarios and the pay-offs of both firms. Clearly, the "Win-Lose" and "Lose-Win" scenarios are not feasible because no firm would sacrifice itself for others. From the project's perspective, the "Win-Win" scenario is the best outcome because this is what a firm would do in the "one-firm-does-all" model. Under risk sharing, however, this scenario is unstable because each firm can be better off by delaying its task regardless of the others' action. Thus, each firm will find every excuse to delay. Although the "Lose-Lose" scenario is the worst outcome for the project, it is indeed stable and the final outcome (as in the Prisoner's Dilemma).

About the Author

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References

1. This research was supported by National Science Foundation (NSF) Awards No. 0747779 and No. 1537591.
2. C.S. Tang, J.D. Zimmerman, "Managing new product development and supply chain risks: the Boeing 787 case," *Supply Chain Forum: an International Journal*, 10/1 (2009): 74-86; S. Kotha, R. Nolan, "Boeing 787: the Dreamliner (B)," Case study, the Foster School of Business at the University of Washington (October 14, 2008).
3. J. Teresko, "The Boeing 787: A matter of materials. Special Report: anatomy of a supply chain," *Industry Week*, (December 2007), see http://www.industryweek.com/articles/boeing_787_a_matter_of_materials_--_special_report_anatomy_of_a_supply_chain_15339.aspx.
4. T.C. Horng, K. Bozdogan, "Comparative analysis of supply chain management practices by Boeing and Airbus: long-term strategic implications," presented at the MIT Lean Aerospace Initiative, (April 18, 2007); Exostar LLC, "Boeing 787: global supply chain management takes flight," Case study (2007).
5. Horng and Bozdogan, op. cit.
6. B. Ulder, "Global Hawk supply chain integration." Presentation at the Aerospace and Defense conference hosted by Aviation-Week and Space Technology, Phoenix, AZ, August 2011; V. Kamath, "Key challenges for supply chain in A&D." Presentation at the Aerospace and Defense conference hosted by Aviation-Week and Space Technology, Phoenix, AZ, August 2010.
7. Horng and Bozdogan, op. cit.; Tang and Zimmerman, op. cit.
8. M. Lee, R. Anupindi, "Boeing: the fight for fasteners," *Tauber Institute Case 1-428-787*, (November 17, 2009).
9. Horng and Bozdogan, op. cit.
10. D. Gates, "Boeing celebrates 787 delivery as program's costs top $32 billion," *The Seattle Times*, (September 24, 2011).
11. P. Lane, "Delivery of the first 777: launching US into the 21st century – Boeing, United celebrate new era," *The Seattle Times*, (May 17, 1995); N. Clark, "The Airbus saga: crossed wires and a multibillion-euro delay – business – International Herald Tribune," *The New York Times*, (December 11, 2006); Gates, op. cit.; X. Xu, Y. Zhao, "Build-to-Performance – The Boeing 787 Dreamliner," Case study, Rutgers Business School – Newark and New Brunswick, NJ, (2010).
12. Kotha and Nolan, op. cit.; D. Turim, D. Gates, "Building the 787 Dreamliner: a timeline," *The Seattle Times*, (December 15, 2009).
13. Tang and Zimmerman, op. cit.; Horng and Bozdogan, op. cit.; A.J. Shenhar, V. Holzmann, B. Melamed, Y. Zhao, "The Challenge of Innovation in Highly Complex Projects: What Can We Learn from Boeing's Dreamliner Experience?" Project Management Journal, 47/2 (2016): 62–78.
14. H. Weitzman, "Dreamliner lessons to shape Boeing direction," *Financial Times*, (September 25, 2011); M. Hiltzik, "787 Dreamliner teaches Boeing costly lesson on outsourcing," *Los Angeles Times*, (February 15, 2011); Kotha and Nolan, op. cit.; Tang and Zimmerman, op. cit.
15. Turim and Gates, op. cit.
16. B. Domke, "Boeing 787 lessons learnt," Airbus, (October 20, 2008), <http://www.planebusiness.com/buzz/airbus2.pdf>; Kotha and Nolan, op. cit.
17. Domke, op. cit.; Kotha and Nolan, op. cit.; Xu and Zhao, op. cit.; Shenhar, Holzmann, Melamed, and Zhao, op. cit.; Lee and Anupindi, op. cit.; Turim and Gates, op. cit.
18. Domke, op. cit.; Kotha and Nolan, op. cit.; Xu and Zhao, op. cit.; Shenhar, Holzmann, Melamed, and Zhao, op. cit.; Lee and Anupindi, op. cit.
19. J.L. Lunsford, "Boeing Scrambles to Repair Problems With New Plane – Layers of Outsourcing Slow 787 Production; 'Hostage to Suppliers'," *The Wall Street Journal*, (Dec. 7, 2007).
20. S. Nahmias, *Production and operations analysis 5th Edition* (McGraw-Hill Irwin, Boston, 2004).
21. B. Holmstrom, "Moral Hazard in Teams," *Bell Journal of Economics*, 13 (1982): 324-340.
22. D. Gates, "Boeing 787 supplier halts work for 24 hours after FAA audit," *The Seattle Times*, (July 2, 2008).
23. S, Ray, "Boeing agrees to buy Vought aircraft 787 operations." Bloomberg news, (July 7, 2009).
24. Lee and Anupindi, op. cit.
25. If Boeing works slowly, it barely incurs any additional cost at that time because the customers are loyal and the damage of contract penalty has already been done (LN 1 is in such a bad shape, there is little hope to get it done within 12 months, and Boeing only has to pay contract penalty for the first 12 months (Wellsfargo Securities, "Equity Research: Boeing Company," (August 11, 2009).). If Boeing makes a significant effort to catch up with the schedule, the suppliers will reap the most of the benefit because at that time, the suppliers were paying for a majority of the development.
26. Exostar, op. cit.
27. Reuters, "A wing and a prayer: outsourcing at Boeing," Special Report, (January 2011); Ray, op. cit.