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STEERING STRATEGIC DECISIONS AT LONDON UNDERGROUND: EVALUATING MANAGEMENT OPTIONS WITH SYSTEM DYNAMICS

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ABSTRACT

System dynamics simulation models provide a powerful and rigorous means of evaluating management options in dynamically complex settings such as a metro subway system. This paper explores how a system dynamics model has been used over several years to address a variety of management challenges at London Underground. Several short case illustrations are described to demonstrate how such models are used in practice to aid strategic decision making, carry out robust business planning, and communicate effectively with key stakeholders.

1 INTRODUCTION

By holistically and comprehensively representing the relevant dynamics and environment, system dynamics simulation models provide a rapid and realistic analysis platform for evaluating a broad range of management "what if" questions. System dynamics models are composed of interlinked cause-effect relationships, and include the time delays and non-linearities that characterize such relationships in real life. Quite uniquely, system dynamics models can capture explicitly the interrelationships and feedback effects that make complex environments so difficult to analyze reliably with other analytical approaches.

PA Consulting Group worked with London Underground Limited (LUL) to develop and exploit a system dynamics model of the Underground. This model has been used to provide insight into a wide array of strategic and operational issues at LUL.

Section 2 of this paper provides a brief overview of the initial situation at LUL, followed by a description of the system dynamics model developed in Section 3. A series of short examples is then presented in Sections 4-6 to illustrate the model's use to aid strategic decision making, carry out robust business planning, and communicate effectively with key stakeholders. Summary conclusions are provided in Section 7.

2 LONDON UNDERGROUND CHALLENGES

LUL is the oldest and second largest metro in the world, with 249 route miles and 10 inter-operating lines. Over 3 million people rely on the transportation provided by the Underground each day. In 1997, the UK Government sought to make up for years of under-investment and to reduce the Underground's reliance on uncertain public funding. It directed LUL to investigate restructuring options that would include private sector involvement.

This government directive to restructure the Underground to bring in private investment launched LUL on a search for a holistic method of analysis that could help evaluate this important business issue. The analytic work which supported restructuring of the Underground into the recently completed Public-Private Partnership (PPP) has been presented previously in Mayo, Callaghan and Dalton (2001).

LUL's business and operating environment is characterized by numerous interactions that operate across functional business areas. Figure 1 illustrates one such set of interactions that cuts across the areas of engineering, finance, service operations, and market planning. This set of relationships forms a self-reinforcing feedback loop: with improved service delivery, passenger volumes will rise, generating more revenue, permitting increased capital investment and procurement of more and better quality assets, thus further

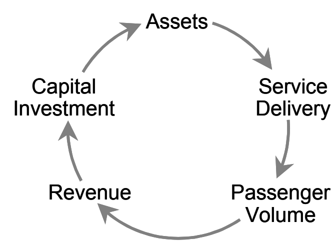

Figure 1: Interactions Operate Across LUL's Business

improving service delivery. Such positive feedback loops can produce beneficial or virtuous behavior, as just described, or can act in the opposite direction (e.g., declining service delivery, decreasing passenger volumes, etc.) to create a vicious circle of declining performance.

LUL had many sophisticated and detailed planning models that focused on individual areas of its business. However these tools could not, in piecemeal fashion, cope with the complexity of such interactions across broad areas of LUL's business to produce a reliable view of how system performance would change under alternative policies. Further, the existing tools did not permit an explicit assessment of how different choices would impact the many stakeholders who populate LUL's environment - including riders, government, employees, and the private sector.

LUL worked together with PA Consulting Group to develop a system dynamics simulation model to provide the missing integrated, system-wide view of the Underground and its key stakeholders. (See Sterman 2000 for an excellent and comprehensive introduction to system dynamics.) The model includes LUL's operations, assets and finances, along with its customers and their choices among competing transportation modes. LUL's Dynamic Simulation Model and its use have evolved over time to accommodate LUL's changing analytical needs.

3 THE LUL DYNAMIC SIMULATION MODEL

Figure 2 provides a high-level sector view of the simulation model, illustrating both the basic content of each sector and the primary interrelationships by which various elements of the Underground interact with stakeholders and other aspects of LUL's environment. Note that this view reflects the "old" integrated LUL (before the PPP was implemented).

The traveling public is represented in the market sector. Riders choose explicitly between the different modes of transport available in Central London. These include the Underground, buses, scheduled train service, private auto-

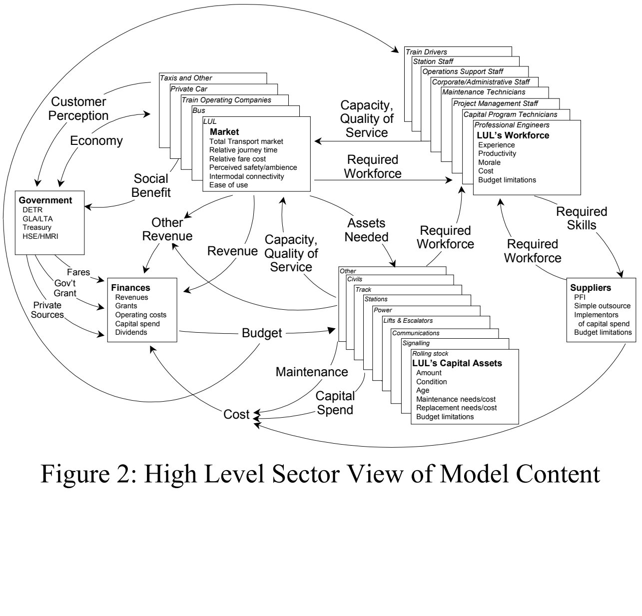

Figure 2: High Level Sector View of Model Content

mobiles, and all other modes (taxi, bicycles, etc.). To make their choice, riders compare the relative attractiveness of these different modes across the travel characteristics they value - particularly journey time, cost, safety, ease of use, ambience, and the convenience of inter-modal connections.

LUL's workforce, physical assets, and suppliers come together to deliver Underground service to this market. LUL's workforce is represented by eight major staff categories (e.g., train drivers, station staff, professional engineers, maintenance technicians, etc.). Each has a role to play in delivering LUL's service to the traveling public. Staff attributes such as productivity, morale, and experience level influence the service delivered by the Underground.

LUL's capital asset base includes ten major categories of assets (e.g., rolling stock, track, stations, escalators etc.) that together make up the infrastructure that enables the delivery of train service. Factors such as the number of assets, their age and condition, maintenance required, and their replacement or renewal via the capital program all influence the quality of service offered to the public. Suppliers principally supplement the skills and resources available within LUL's workforce to perform maintenance and capital program work on the asset base, and provide this assistance to LUL under a variety of contractual regimes.

The government sector captures the interests and actions of UK Government bodies. Here, decisions regarding levels of grant funding, access to private capital, fare levels, and transport policies are incorporated as key aspects of LUL's environment.

Finally, LUL's financial performance depends primarily on revenue and operating costs, and determines the funds subsequently available for capital spending. Budget limitations exert downward pressure on staff hiring and spending on the capital asset base.

Figure 3 shows another view of the same Underground system, now with an emphasis on communicating the underlying dynamics that act across the sectors just described.

The quantitative system dynamics model was built and numerically calibrated to recent LUL history. Validation and calibration of the model structure and parameterization were carried out as an important and integral part of the development process. Key simulation outputs were checked against "hard" time-series data wherever possible, for the period from 1992 through 1999. These data included items such as train and passenger kilometers delivered, revenues, costs, headways achieved, number of assets by category, number of staff by category, and the like. In addition, the simulation of many important "soft" factors such as staff morale and the public's perception of personal security on the Underground were compared to the first-hand knowledge of LUL staff experts. During development, many LUL staff reviewed the model's output for reasonableness, and helped determine the causes of discrepancies between the simula-

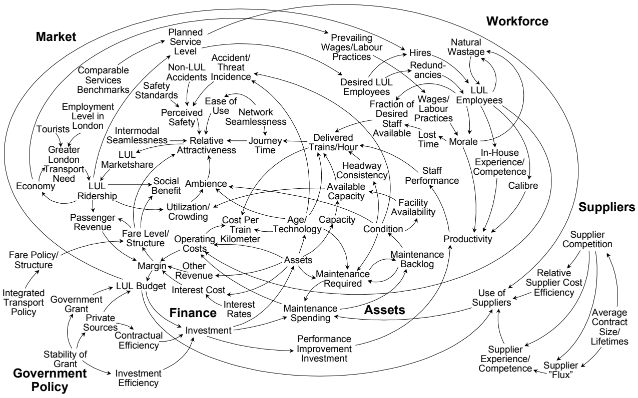

Figure 3: A High Level View of Key Dynamics Driving LUL's Performance

tion and actual historical performance. Figure 4 shows several examples of the simulation compared to LUL's actual historical performance - for passenger kilometers (top left), train kilometers (top right), total Underground staff (lower left), and percent of rolling stock assets available for service (lower right). In each plot, the solid line is the model simulation and the dotted line is actual data used for comparison.

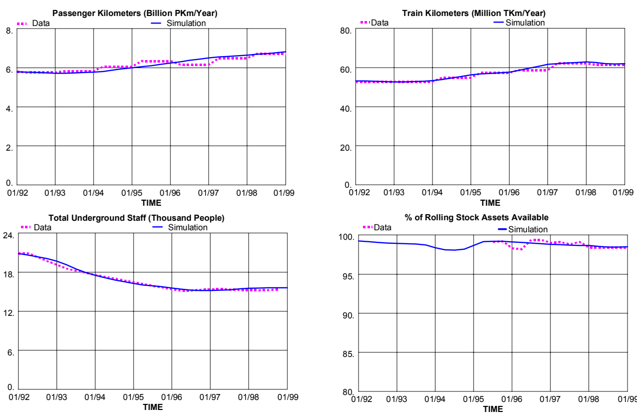

Figure 4: Examples of LUL Model Calibration

As noted by Lyneis (1999), accurate calibration can greatly enhance user confidence in a simulation model. It has been powerfully convincing to LUL to see that the model's cause-effect structure recreates LUL's actual historical performance - and in particular, for the right underlying reasons and without any interim data-driven adjustments. Achieving this level of fidelity made the model more credible to LUL executives who were not close to its development, yet could benefit from its analytical capability. As a result, many more people at LUL had the interest and confidence to engage with the model and to benefit from its use than would have otherwise been the case.

The following sections provide examples of three of the many ways that the model was used at LUL - to support making key strategic decisions, to conduct robust business planning, and to facilitate effective communication among stakeholders.

4 STRATEGIC DECISION MAKING

Due to budget problems elsewhere in London Transport (LT, LUL's parent organization), LUL was asked to cut its operating costs to increase its gross margin. LUL wanted to cut costs in a way that would produce the least damage to ridership and social benefit levels, in both the short- and long-term. So before agreeing to the Board's request, the model was used to analyze how a variety of cost cutting options would affect service levels, ridership, revenues and other aspects of system performance into the future.

There were several cost cutting approaches that LUL could take, including pure efficiency improvements, straight "across the board" style cuts, cuts targeted to specific areas, and combinations of these. The key questions were: Is there a way to cut costs now that does not promulgate further cost pressure – and thus the need for more cuts – in the future? What areas should be cut, by how much, and over what timeframe, to meet the multi-year targets? And how would future performance be affected by each of the cost cutting options?

Numerous simulations were conducted to evaluate the full consequences of various cuts on system performance. Simulations showed that pure efficiency gains alone, while the most attractive in terms of preserving ridership and social benefit levels, could not realistically generate the cost savings sought within the six months available. Clearly then, some operating areas would need to be cut. But which areas and by how much?

Additional analyses demonstrated that taking a simple "across the board" approach to cuts would cause significant and lasting damage to LUL. Some of the key feedback relationships that generate a spiral of declining performance are shown in Figure 5. As cost cuts are applied to the various operating categories (for example to maintenance and staff levels), the impact flows "downstream" over time to impact service elements that matter to customers. For example, as journey time increases and ambience declines, this depresses the attractiveness of LUL service relative to alternative transport options, leading to declines in ridership and revenue, eventually creating more pressure to cut costs!

The model was then used to search for alternative packages of cuts that would balance improved near term margin performance against maintaining service quality and staving off the need for additional cuts in the future. Several packages were identified that struck a better compromise between these competing objectives. However, there were no options that would be "pain free" – all viable options for cost cuts would sacrifice future performance for the sake of the requested near-term gross margin boost.

The nature of the tradeoff LUL faced is illustrated in Figure 6, which shows the simulated gross margin trajec-

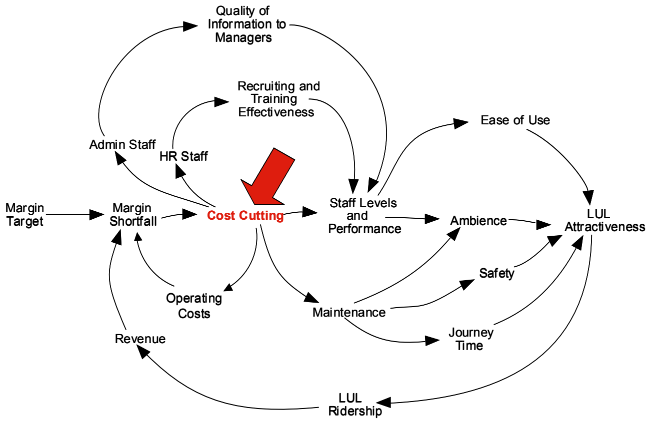

Figure 5: Cuts that Impact Service Quality Reduce Ridership and Revenue, Forcing the Eventual need for Additional Cuts

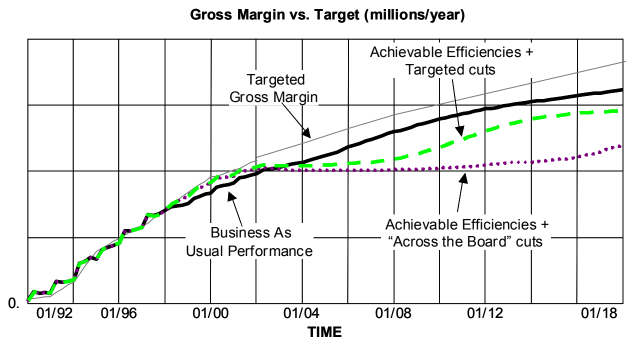

Figure 6: LUL Faced a Tradeoff Between Short- and Long-Term Performance

tory into the future under three different scenarios: Business as usual performance (where there are no cuts made to meet the higher gross margin target), Achievable Efficiencies + "Across the Board" cuts (where savings come from achievable efficiencies and proportional cuts to all expense categories), and Achievable Efficiencies + Targeted cuts (where savings come from achievable efficiencies and cuts targeted to specific cost areas). Future performance was evaluated in terms of passenger levels, service delivery, maintenance performed and resulting asset condition, and many more attributes of LUL's system performance. Though targeted cuts were clearly preferable to "across the board" cuts, the fact remained that performance over the long term would be much better if cuts could be avoided now.

At first glance, this issue may have appeared to require a simple and straightforward spreadsheet analysis. owever, simulations with the system dynamics model showed how ignoring critical feedback effects would lead to incorrect conclusions and negative consequences for the Underground. In particular, the analysis showed that system performance, in terms of ridership, revenue, and service delivery, would be sacrificed for years to come under any of the cost cutting plans. The LUL Managing Director used these results to demonstrate the nature of the short- and long-term tradeoff that such cuts would force LUL to make. In response, the LT Board rescinded its request for cuts from the Underground.

5 ROBUST BUSINESS PLANNING

LUL's Dynamic Simulation Model was also used to support the development of sound business plans for the three infrastructure companies ("Infracos") that were being established for eventual handover to the successful private sector bidders in the PPP. This meant a complete restructuring of London Underground with the Infracos run as largely independent businesses, although still owned by LUL in the interim. Each Infraco was led by experienced engineering managers, who early on had to develop robust plans for their new and unfamiliar businesses. Each of the three teams brought to bear previous experience and skills in long-term planning, exhibiting different rates of progress and levels of confidence. One team believed they had a complete and robust plan while the other two were still actively exploring ideas and alternatives.

The issue for London Underground's corporate management was the extent to which these plans (which would also be made available to the private sector bidders) could be shown to be coherent and feasible. Key questions included therefore: Did the plans contain any significant inconsistencies or rely upon unreasonable assumptions? How robust were they in the face of potential risks? And what refinements to the plans would make them more durable and robust?

The system dynamics model provided an ideal vehicle to address these questions, because it provided a comprehensive and internally-consistent view of the Underground, and therefore enabled simultaneous exploration of the key elements of staffing, assets and financial performance. To use the model's "what if" capability to answer questions about each business plan, the first step was to produce a baseline simulation that recreated the expected performance for each plan, using a set of assumptions to characterize how the Infraco intended to operate.

Some of these assumptions were "explicit" – for example, intentions to alter maintenance operations or execution of the capital program to produce savings relative to the current regime, or plans to purchase new assets with specific technologies as part of the line upgrades that Infracos would deliver. Other assumptions were "implicit" – unstated assumptions which, for internal business plan consistency, would also have to be true to produce the expected outputs of the plan.

The process to create the baseline business plan simulations followed these basic steps:

1. The explicit assumptions of each business plan were ''input'' to the simulation model to create an initial scenario roughly characterizing the business plan.

2. The performance in this initial simulation was compared to the stated outputs of the business plan, for instance the planned spending on station assets over the 10-year planning period, planned operating cost levels and the like.
3. The cause–effect structure of the system dynamics model was then used to examine differences between the outputs shown in the plan, and those simulated by the model. The objective was to identify and estimate parameters not explicit in the plans, but which must necessarily have been assumed for the plans to be internally consistent. The model parameters were then adapted iteratively until the model replicated the performance characteristics of each plan.

Using the resulting simulations, simulated system performance (e.g., staffing levels, service delivery on that Infraco's portion of the Underground network, profits etc.) for each business plan could be reviewed. A "causal analysis" was developed, highlighting the differences between current and future practice which would have to be achieved for the business plan outcomes to be realized.

Using the model to expose to view these implicit assumptions gave the management teams valuable insights that could not have been determined in any other way. In particular, it rapidly identified unreasonable or overly aggressive assumptions (e.g. exceeding the level of performance capability that could be realistically delivered with the underlying asset fleet) and potentially unrealistic conditions (e.g. delivering the planned capital program even though it implied a near doubling of program staff within a one year period) that were needed to execute that business plan successfully.

Figure 7 shows outputs from one of many simulation tests conducted as part of the planning. In this case, the Infraco was concerned about the implied increase in staffing required to deliver the planned phasing of station works.

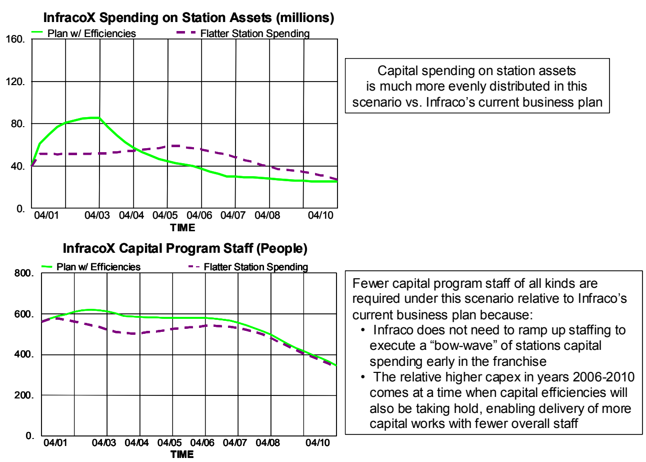

Figure 7: Evaluating Alternative Capital Spending Profiles and the Impact on Staffing Levels

The top graph in Figure 7 shows the original level of station works (solid line) against an alternative, flatter profile of station works (dotted line). The bottom graph in Figure 7 shows the corresponding level of capital program staff under these two scenarios. The model was used to test alternative phasing of works, to evaluate the impact on staffing levels and other key aspects of performance and achievability, and throughout to explain the dynamics behind the simulated profiles. By testing alternatives and iteratively refining the plans, the Infracos avoided what would have been very poor choices and instead built their plans around sound assumptions which would yield positive outcomes for their businesses.

In effect, these simulations allowed the Infracos to "walk through the future" of their businesses by reviewing the interrelated trajectories for staffing, spending, service performance, and financial performance. Perhaps most importantly, simulation provided a base point from which to test the impact of other ideas, singly and in combination, and to steer refinements to make the business plans more robust.

6 COMMUNICATING EFFECTIVELY WITH KEY STAKEHOLDERS

As a last example, LUL's Dynamic Simulation Model was also used to convey critical information about the Underground - and in particular the factors vital to strong service delivery - to the bidders for the private sector infrastructure companies to be created under the PPP.

The complex range of interactions which combine to determine the performance of the Underground, and the length of time which some dynamics take to manifest themselves (as described earlier) led LUL to make bidders' understanding of key cause-and-effect relationships an explicit factor in bid evaluation. LUL provided a huge amount of information to bidders in the data room, including e.g. asset registers, headcount data, and financial projections. But bidders had only five months to prepare their initial bids, and were likely to fall back on planning approaches similar to those which led LUL's own engineering managers to sometimes unrealistic expectations. LUL believed bidders might struggle in the time available to create for themselves the "big picture" understanding which LUL had derived from the simulation model, and might therefore fall prey to performance pitfalls that analysis had shown must be avoided to produce a successful implementation of the PPP.

Analyses had confirmed repeatedly that "what was good for LUL was good for the Infracos" in that the same factors critical to LUL's ability to deliver high quality service to customers were also those that held the key to strong business performance for the bidders. In particular, four factors – maintaining and improving asset health from the start, maintaining workforce continuity, strengthening working level collaboration and partnership, and fully meeting the requirements of the performance regime –

made most of the difference between a successful and a poor implementation of the Underground's restructuring.

LUL's general assertion that what was good for itself was good for bidders may not have been a surprise, since the contract was designed to align incentives on both sides. But making sure the bidders understood and internalized the factors key to their own success was more of a challenge and concern to LUL.

To get these important messages across to bidders, materials were developed to make the model's content and key lessons accessible to a non-technical audience. These included a set of brief papers tying the most critical implementation imperatives directly to infrastructure company financial performance, documentation of the model's structure and assumptions to explain "how the Underground works", and an interactive version of the system dynamics model so bidders could themselves simulate key dynamics and test out different strategies for managing infrastructure companies. These materials were all issued along with the official invitation to tender documents. A series of facilitated workshops held throughout the bid development period enabled the bidder teams to use the model and related materials effectively. These materials are visualized in Figure 8.

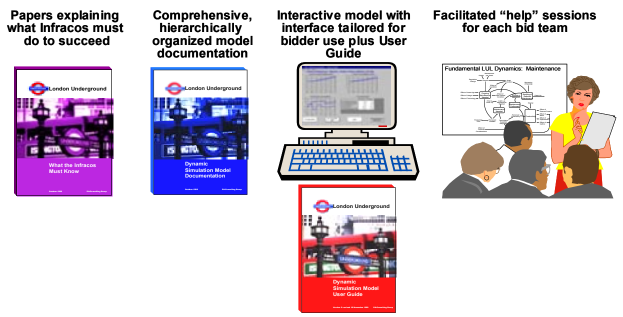

Figure 8: Model-Based Materials Used to Communicate With Bidders

LUL used its Dynamic Simulation Model to convey to bidders its own view of how the Underground works, and to reinforce the importance of factors most critical to future LUL and bidder success - thus encouraging the submission of responsible and realistic bids. At the same time, LUL acknowledged the validity of different approaches the bidders might take to managing their parts of the Underground, and even gave them the "what if" capability to test out these strategies in a risk-free environment. But perhaps most importantly, LUL's communication to bidders of its strongly-held beliefs was elevated from mere assertion to a higher level including a well-reasoned and comprehensively justified explanation of *why*.

7 SUMMARY

The examples provided in this paper illustrate three valuable ways in which a comprehensive system dynamics model can help with major management challenges faced by a complex organization such as London Underground. In the areas of strategic decision making and robust business planning, such a model provides a reliable platform for exploring comprehensively the full consequences of management choices in advance of committing to action, and for refining before implementation the most appealing options. Such a model can in essence "supercharge" the decision making and planning processes, making them simultaneously faster and more reliable than in organizations that rely on a combination of piecemeal analytics and gut instinct.

Communicating effectively with and persuading relevant stakeholders is a vital component of creating actionable strategy. The cause-effect structure of the model and the breadth of environment that the system dynamics method can accommodate helps unite disparate groups around a common view of the key drivers of performance, thereby creating a shared language for discussing their interests and goals. Importantly, the ability to demonstrate quantitatively the implications of different management choices in the stakeholders' own terms can be a tremendous aid in securing commitment to action, whether across functional units within a single company or across multiple organizations.

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