

Interdependence of Technology and Work Systems:
A Baseline Memo for the MIT Work of the Future Task Force

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The purpose of this “baseline memo” is to summarize prior evidence on the interrelationships between technology and work systems and related management practices and their effects on economic performance. While the evidence is mostly drawn from earlier generations of technologies, our hope is that it provides a starting point for testing hypotheses about how current and future digital technologies will affect organizational and employee outcomes.

Early Work on Socio-Technical Systems

Theorizing about the interdependence of technology and social systems can be traced back at least as far as the socio-technical theorists (STS) who studied mining in the 1950s such as Trist and colleagues (Trist and Bamford, 1951; Mumford, 2006). A review of more than one hundred STS projects from the 1970s reported that interventions were most successful when technological changes were combined with work redesigns (Pasmore, et al, 1982). A second wave of evidence on the relationships of technology and organizational practices and their individual and joint effects on productivity and product quality came from research in the auto industry in the 1980s and 1990s.

Lessons from the Auto Industry

In 1980 NBC produced a documentary titled “If Japan can do it, why can’t we?” It focused on the growing awareness that Japanese manufacturers, and Japanese automakers in particular, were producing and selling products of higher quality with higher productivity than many of their American competitors. Thus began a decade of soul searching over why this was the case that generated a host of responses aimed at closing the productivity and quality gap. No industry felt this pressure more than autos, and no industry tried more different things or received closer scrutiny from the public and from academics.

General Motors was the first to respond aggressively to the Japanese challenge. Its answer to NBC’s question was, yes the U.S. industry could do it too, but in its own way—with heavy investment in the most modern, advanced technology money could buy. Over the decade of the 1980s, GM spent upwards of \$50 billion on advanced technologies for its plants. Visitors to some of GM’s high technology plants such as its Hamtramck facility in Michigan, or its Wilmington, Delaware plant could see the wizardry and complexity of the automated tracking systems that guided parts to their appropriate spot on the assembly line and the high-tech robots. Too often, however the robots were standing idle, under repair, or in some cases moved off the assembly line for workers to get the job done the old-fashioned way. As a result, GM learned a lesson, one that two MIT students would later quantify. The lesson was that you could not simply automate your way to high productivity and quality. At the end of the decade after spending \$50 billion, GM was still the highest cost car manufacturer in America.

NUMMI and its Legacy

¹ Portions of this memo are taken from a 2007 teaching memo by Thomas Kochan and Joel Cutcher-Gershenfeld.

Why did the investments in technology not pay off? Part of the reason may have been that the automation was premature and poorly designed. It was too rigid to adapt to variations in product specifications and it simply automated inferior production systems and practices. However, a set of case studies conducted by a Japanese colleague visiting at MIT at the time suggested a deeper reason. In 1986, Professor Haruo Shimada from Keio University teamed up with MIT graduate student John Paul MacDuffie and visited the Japanese “transplants” of the Honda, Toyota, and Nissan (auto assembly plants) in the U.S. that had opened in the early 1980s. Their objective was to understand what was different about the production and human resource/labor relations practices of these plants compared to traditional American plants. Their key insight was that the starting assumptions of engineers who built these production systems were fundamentally different.

American engineers saw the hardware features of technology and production systems as separate from their human features. The American engineers’ conception was that the human features were sources of unpredictable variance that should be minimized. Japanese production engineers on the other hand viewed technology as embodying both hardware and human features. Shimada used the term “humanware” to describe this approach to technology and borrowed a phrase from another Japanese scholar who saw humans not as a source of error variance but as a force for “giving wisdom to the machines.”

Figure 1 illustrates the interdependent technical and social/human dimensions of the production system they saw in these auto plants (Shimada and MacDuffie, 1986). Skills, motivation, and flexibility/adaptability were seen as the three key human features that supported the just in time production and inventory control, in line quality control, and other aspects of the technical components of the production system. In turn, supportive human resource practices dealing with selection, training, job assignment, and labor relations were needed to achieve and sustain the required worker attitudes and behaviors.

While Shimada and MacDuffie’s case studies provided the initial qualitative understanding of Japanese transplant production and human resource practices, the first hard data showing the results of these systems came from John Krafcik’s case study of New United Motors Manufacturing Inc (NUMMI) and his comparisons to other U.S. plants. NUMMI, a joint venture between GM and Toyota, was set up in 1982 to produce compact cars for both companies. Toyota was to manage the new organization in a former GM plant in Fremont, California that had been shut down two years earlier. Fremont had the reputation as one of GM’s worst plants in terms of productivity, quality, and labor relations. This was a two-way learning experiment. For Toyota, it was a chance to see if a U.S. workforce and a U.S. supply base could support what was coming to be known as the Toyota Production System (TPS). For GM, it was a chance to learn more about this new production system.

The NUMMI story is so much a part of industrial folklore in the auto industry (Adler, 1992; Levine, 1995; Wilms, 1996) that we need only summarize the punch line here. Within two years of the restart of this plant under Toyota’s management, production system, and labor relations, the same union leaders, largely the same workforce, and with only incremental investments in new technologies had become the most productive and highest quality auto producer in the U.S. The data displayed in Figure 2 illustrate this finding. This is a table that was generated by John Krafcik’s research at the MIT International Motor Vehicle Research Program for his Master’s thesis in 1988 (Krafcik, 1988). We have used this table numerous times in courses with Senior Executives at MIT, some of whom were from GM

or other parts of the auto industry. Showing these data, reinforced the notion that a “picture is worth a thousand words.” Repeatedly executives who were skeptical of the powerful difference high trust, participative, flexible, secure, well trained and properly led workers could make came over to accept the reality. Labor-management relations, when combined with a production system that emphasized quality, flexibility and continuous learning, and integrated technology and human resources, could produce, in the U.S. what Krafcik called “world class manufacturing,” what Paul Adler (1992) called a “learning bureaucracy,” and what later was labeled “lean production” (Womack, Jones, and Roos, 1990).

While the NUMMI results were impressive and good for teaching, two questions remained unanswered. First, what actually accounted for these differences? Was there some single “silver bullet” feature of the NUMMI design that could be replicated elsewhere with the same results? Or was it the full NUMMI model that mattered, and if so, what are the key features of the model? Second, to what extent are these results generalizable, either to other auto plants or to other industries? A decade of research that followed addressed these questions.

Evidence on High Performance Systems and Complementarities

John Paul MacDuffie (MacDuffie, 1995; MacDuffie and Krafcik, 1992; MacDuffie and Pil, 1997) built on the Shimada and MacDuffie case studies and the Krafcik methodology for comparing productivity of assembly plants by conducting an international assembly plant study. They measured and estimated the individual and joint effects on productivity and quality of automation and other elements of the production system along with work organization and human resource practices. They found that indeed the results generalized and that again worldwide, it was not the most automated plants that produced the highest productivity and quality but those that integrated flexible automation with flexible work systems and supportive human resource practices. Moreover, they showed that it was the joint effects of systems that “bundled” together the elements in Figure one—both the technical and social/human features that produced these results.

Meanwhile similar evidence for this “bundling” or “system” effects were appearing in studies of work systems and human resource practices in other industries such as office products (Cutcher-Gershenfeld, 1991), steel (Ichniowski, Shaw, and Prensushi, 1997), telecommunications (Batt, 1999) and other industries. Over the course of the 1990s, similar results were published from studies in the apparel, metalworking, trucking, airline, and semiconductor industries (Ichniowski, Kochan, Levine, Olson, and Strauss, 1996). The terms “high performance work organization” or “knowledge based” work systems, became the popular labels used to characterize these systems. Their common feature was that the combination of elements outperformed the individual elements. In this same time period Milgrom and colleagues formalized this argument around the concept of “complementarities” in production systems Brynjolfsson and Milgrom (2013).

Evidence from IT

MIT Nobel Laureate in economics Robert Solow famously quipped that one could see computers everywhere except for the productivity numbers. This was because the growth of labor productivity (real GDP per hour) slowed significantly in the US after the 1970s oil price shocks. This was at a time when there was rapid diffusion of Information and Communication Technologies (ICT) such as the personal computer. This “productivity paradox” was seemingly resolved by two developments. First, at the macro-economic level US productivity growth broadly doubled in the decade following 1995 (this

was the so-called “productivity miracle” period). Second, at the micro-level, large numbers of plant, firm and industry studies began to find important correlations between productivity and ICT (see the survey by Draca, Sadun and Van Reenen, 2007, for example). These studies typically use largescale panel databases and perform econometric analysis rather than being based on case studies.

A striking finding from these micro studies was that the impact of ICT on performance was highly variable. Many firms could spend huge amounts on computers with little effect on productivity, whereas others could spend relatively little and achieve impressive results. The explanation of these heterogeneous effects seemed to rest in the same factors discussed above. Firms who could manage and re-organize their themselves to make better use of the new technological opportunities were the ones who reaped rewards. Using publicly listed US firms, Bresnahan, Brynjolfsson, and Hitt (1999) found that higher productivity was achieved from joint investments of IT with innovations in work systems and human resource practices than with investments in IT or human resource/work system practices alone. Caroli and Van Reenen (2001) found similar results in France and the UK.

To bridge the link between micro and macro studies, Bloom, Sadun and Van Reenen (2012) combined the firm-level measures of management practices developed by Bloom and Van Reenen (2007) with detailed ICT data. They found that ICT increased productivity on average, but only when firms had excellent people management practices (e.g. worker engagement, careful hiring/firing and merit based pay and promotion practices). Improving these organizational practices could bridge half of the productivity growth gap between the US and EU in the productivity miracle period.

Evidence from Health Care

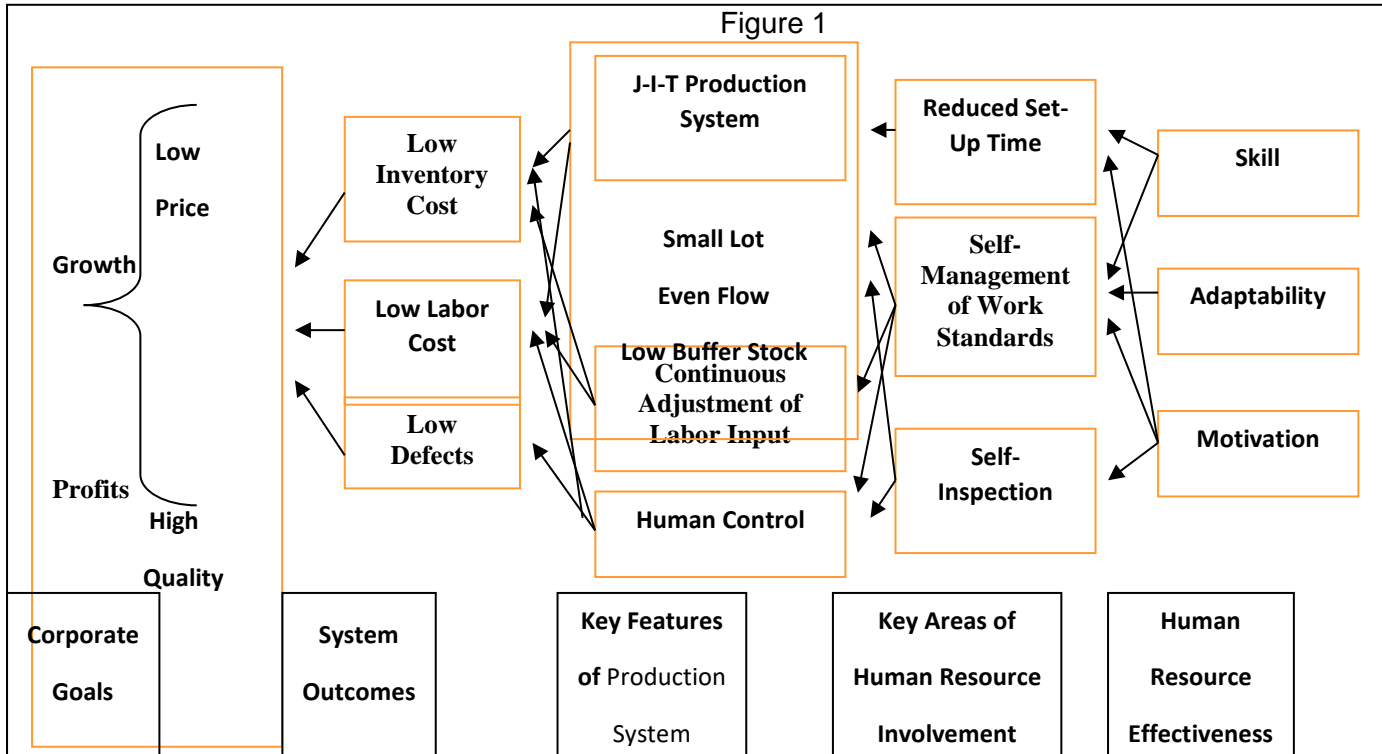
Litwin (2011) and Hitt and Tambe (2016) documented similar effects of the complementarity between technology and organization in health care.

Task Force Implications

The bottom line of this line of research suggests that by attending to these micro social and human resource aspects of work systems and integrating them with the appropriate technical or hardware tools and resources, “world class” levels of productivity and quality can be achieved. Whether or not these findings will generalize to current and future technological innovations/investments is an open empirical question, one worthy of incorporating into the Work of the Future Task Force agenda. Indeed, this earlier work is very closely related to emerging research on human-robot interactions, collaborative robotics, and related concepts and ideas that a number of Task Force members are now pursuing.

There are at least two lessons relevant for the impact of the technologies of the “Fourth Industrial Revolution (such as AI and robotics) from the Third (ICT-based) Industrial Revolution. First, technologies create threats and opportunities for productivity and jobs. How these play out is at least in part, an organizational choice of the firm and society. Second, it takes time for these things to have a practical effect. It was decades before the theoretical impact of electricity (a Second Industrial Revolution technology) had a discernible impact on productivity and the same was true of computers. Although it

may be that this time is different, the impact of AI may also take much longer than people expect to impact on the labor market.



Source: Haruo Shimada and John Paul MacDuffie. *Industrial Relations and "Humanware."* (Sloan School of Management Working Paper 88-01)

Figure 2-1
NUMMI Compared to other Auto Plants (1986)

	Productivity (hrs/unit)	Quality (defects/100 units)	Automation Level (0:none)
Honda, Ohio	19.2	72.0	77.0
Nissan, Tenn.	24.5	70.0	89.2
NUMMI, Calif.	19.0	69.0	62.8
Toyota, Japan	15.6	63.0	79.6
GM, Mich.	33.7	137.4	100.0
GM, Mass.	34.2	116.5	7.3

Productivity: standardized number of man-hours to weld, paint and assemble a vehicle.
Quality: defects attributable to assembly operations reported in first six months of ownership.

Automation level: robotic applications/production rate, normalized to 100 for highest level in the group.

Source: John Krafcik, "Triumph of a Lean Production System," *Sloan Management Review*, 1988, Vol. 3, pp. 411-52

References

- Adler, Paul, "The Learning Bureaucracy: The New United Motors Manufacturing Inc.," in Larry L. Cummings and Barry M. Staw (eds.) Research in Organizational Behavior, vol. 15, Greenwich, CT: JAI Press, 1992, pp. 180-205.
- Batt, Rosemary,, "Work Organization, Technology, and Performance in Customer Service and Sales." *ILR Review* 52 (4), 1999, 539-564.
- Bloom, Nicholas, Raffaella Sadun and John Van Reenen (2012), "Americans Do I.T Better: US multinationals and the productivity miracle" *American Economic Review* 102 (1), 167-201
- Bloom, Nicholas and John Van Reenen (2007), "Measuring and Explaining Management practices across firms and nations" *Quarterly Journal of Economics* 122(4), 1351–1408.
- Bresnahan, Timothy F., Erik Brynjolfsson, and Lorin M. Hitt, "Technology organization and the demand for skilled labor," in Margaret Blair and Thomas Kochan (eds.) The New Relationship, Washington, D.C.: The Brookings Institution, 1999, 145-84.
- Brynjolfsson, Eric and Paul Milgrom, "Complementarity in Organizations. In Robert Gibbons and John Roberts (eds). *The Handbook of Organizational Economics*. Princeton: Princeton University Press, 2013.
- Caroli, Eve and John Van Reenen (2001) "Skill biased organizational change? Evidence from British and French establishments" *Quarterly Journal of Economics* CXVI, No. 4, 1449-1492
- Cutcher-Gershenfeld, Joel, "The impact on economic performance of a transformation in workplace relations." *Industrial and Labor Relations Review*. 44, 2, 241-260, 1991.
- Draca, Mirko, Raffaella Sadun and John Van Reenen (2007), "ICT and Productivity" Handbook of Information of Information and Communication Technologies" R. Mansell, C. Avgerou, D. Quah and R. Silverstone (eds) Oxford Handbook on ICTs, Oxford University Press
- Ichniowski, Casey, Levine, David, Thomas Kochan, Craig Olson, and George Strauss, " What works at work: An Introduction," Industrial Relations, 1996.
- Ichniowski, Casey, Kathryn Shaw, and Giovanna Prennushi, "The effects of human resource management practices on productivity: A study of steel finishing lines." *American Economic Review* 87, 3. 291-313, 1997.
- Hitt, Lorin M. and Prasanna Tambe, "Health care, Information technology, work organization and nursing home performance, *Industrial and Labor Relations Review*. 69, 4, 824-859, 2016.
- Kochan, Thomas and Joel Cutcher Gershenfeld, "Integrating Social and Technical Systems: Lessons from the Auto Industry." (Unpublished document, MIT August 2007)
- Krafcik, John F., "Triumph of a lean production system," Sloan Management Review, 3, 411-452, fall, 1988.

Litwin, Adam Seth, "Technological change at work: The impact of employee involvement on the effectiveness of health information technology." *Industrial & Labor Relations Review*, 64(5), 863-888, 2011.

MacDuffie, John Paul, "Human resource bundles and manufacturing performance: organizational logic and flexible production systems in the world auto industry," *Industrial and Labor Relations Review*, 48, January 1995, 197-221.

MacDuffie, John Paul and John F. Krafcik, "Integrating technology and human resources for High-Performance Manufacturing: Evidence from the international auto industry. In Thomas Kochan and Michael Useem (Eds.) *Transforming Organizations*. MIT Press, 1992; 209-226.

MacDuffie, John Paul and Fritz Pil, "Changes in auto industry employment practices: An international overview," in Thomas A. Kochan et al (eds.) *After Lean Production*. Cambridge: MIT Press, 1997, 9-44.

Mumford, E. "The Story of Socio-Technical Design: Reflections on its Successes, Failures, and Potential." *Information Systems Journal* 16, (4), 2006, 317-342.

Pasmore, W. C. Francis, J. Haldeman, and A. Shani, "Sociotechnical Systems: A North American Reflection on Empirical Studies of the Seventies." *Human Relations* 35, (12), 1982, 1179-1204.

Shimada, Haruo and John Paul MacDuffie, "Industrial Relations and Humanware," MIT Sloan School of Management Working Paper, September 1986.

Trist, Eric and Ken Bamforth, "Some social and psychological consequences of the long wall method of coal getting." *Human Relations*. 4, 1, February 1951, 3-36.

Wilms, Welford, *Restoring Prosperity: How Workers and Managers are Forging a New Culture of Cooperation*, New York: Times Business, 1996

Womack, James, Daniel Jones, and Daniel Roos, *The Machine that Changed the World*. New York: Rawson, 1990.