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The Iridium communications satellite: an artefact, system and history in the 1990s

'Well, Iridium was basically Bary [Bertiger's] idea. He came in with this one-line idea. [Laughter] You could describe it in one sentence, you know, about a small satellite system to effectively have a space-based cellular radio system. It was just an idea, a one-line idea...'

Kenneth Peterson, Motorola engineer and co-inventor of Iridium, NASM Oral History Interview, 2000

'This is not just a phone; it is a vision.'

Robert Kinzie, Chairman, Iridium, Inc., 1992

Introduction

Let's start with an unsurprising claim: the collecting of, display and meaning given to artefacts in technology museums is inseparable from historiography – the narratives, explanations and concepts historians employ to talk about history. But this claim of 'inseparableness' is not without its tensions – despite the fact that academically-trained historians often are those who preside over artefacts in museums. One such tension concerns the status of the artefact in history, a central question for a museum, often peripheral for the discipline of history of technology.[1] Is the artefact evidence, a material entrée into the fine-grained world of inventor, problem and creative response? Or, does it stand (primarily or merely) as reminder, an expression of authenticity, a concrete symbol of an achievement or failure, a person, or historical moment – a representation of the interplay between innovation and culture? If an artefact's value and meaning lean towards the textual, symbolic or cultural, the museum seems to lose the possibility of a distinctive, fundamental role in the history of technology as discipline. The museum and the artefact each become one more conveyor of texts in a culture defined by texts. In this view, artefacts perhaps serve the same illustrative purpose as the several pages of photographs tucked into a typical academic or general-audience history book. They are not in and of themselves as material objects a source through which the discipline creates narratives of explanation or accounts of historical change.[2]

The artefacts 'tension' suggested in this simple characterisation has two roots. One is *historiographic*: the fundamental explanatory orientation of the field has shifted. Internalist history, with its focus on discrete, material, geographically and time-bounded acts of innovation by a lone inventor or by small groups, long ago yielded to a culturally-oriented historiography. For the latter the goal has been to explain cultural change – the ways in which the specifics of innovation, and more broadly the activities of science and technology, both embody and participate in the making of culture. In the shift to 'culture' the causes and contexts of innovation seem less easily bounded.[3]

The second aspect of the problem of the artefact is *historical*: different periods of history raise different considerations on how to relate innovation, artefacts and culture. In the Cold War era and its commercial, globally-oriented aftermath, the organising concept of system has been central to many technologies, especially space technologies – the US ballistic missiles programmes and Apollo programme are well-known exemplars. This systems emphasis has deep implications for technology museums. Individual artefacts so situated derive meaning primarily in the context of the system of which they are a part. Such systems, often state-sponsored, sporting big budgets, and using skills and materials from many institutions, often have been vast cultural enterprises, explicitly composing and intermingling ideology, politics and technology. Even more, authors including Thomas Hughes, Langdon Winner and Ulrich Beck have argued, in different ways, that post-Second-World-War systems in their many interlocking manifestations define a new mode of personal and social life.[4] In this historical frame, individual artefacts thus testify to multiple and complex acts – with those that are textual often predominating (in number and importance) over those that are material or directly centred on the artefact. To the degree one might discern the discrete bounded acts of innovation characteristic of internalist historiography, they are embedded in an extended web of cultural and political choices and assumptions.

This essay is an exploration of one such system artefact – an Iridium communications satellite. The Smithsonian's National Air and Space Museum artefact (Colour plate 9) was the first of tens of Iridium satellites constructed by Motorola, a US Fortune 500 company. The satellites were and are signature components of a global, space-based cellular telephone system developed, built and orbited from the late 1980s to the late 1990s – a system still in operation into the twenty-first century. The museum satellite and its in-orbit companions bridge the Cold War era and its aftermath, a period in which private markets and corporations entered into big technology projects, complementing or supplanting state-sponsored initiatives and creating new combinations of the technical and cultural. This essay aims to trace the web of acts and meanings that link the Iridium satellite as artefact, system and culture in the 1990s. Three overlapping yet contrasting frames of reference will be emphasised: the satellite as symbol of post-Cold War culture, especially in terms of innovations in communications as a defining element of that culture; the satellite as exemplar of systems; and, lastly, as a challenge in manufacture.

Born together: Iridium and the post-Cold War moment

The Kenneth Peterson quote at the beginning of the essay suggests that Iridium came into the world via a classic act of heroic invention – at least according to Iridium lore. In 1987, three engineers at Motorola – Kenneth Peterson, Raymond Leopold and Bary Bertiger – grappled with a problem posed by Bertiger's spouse: why could you not make a phone call while sitting on the beach in the Bahamas to your office in the US (or elsewhere)? The question combined the burgeoning expectations for cellphone technology (then confined to major urban areas) as well as the emerging information-era sensibility of monitoring and controlling professional responsibilities while engaged in leisure activities. In response, the three conceived the idea of a space-based, global system of satellites to provide a cellular telephone service to any point on the Earth's surface, sketching and handwriting the concept on a couple of sheets of paper (Figure 1). In this narrative, their idea gained material expression 11 years later in 1998 through an imaginative response to a problem, perseverance, luck and timing.[5] These graphics from the mid-1990s convey two perspectives of Iridium as system – as satellite constellation (Colour plate 10) and as communications system that could act independently of and integrate with ground-based telephone networks (Figure 2).

Two aspects of the 1987 'eureka' bear mention. One is that the idea from its inception focused on a complete system – not a component or portion of a system (such as a satellite). The primary inventive act was conceptual, unrelated to any specific material, technical problem – it was oriented toward envisioning a future market.

The second aspect is contextual. The three Motorola inventors worked as part of a relatively small Systems Engineering Group situated within Motorola's Government Electronics Division devoted to contract work building electronic subsystems for military and intelligence programmes primarily, as well as for NASA projects. The division was a small slice (approximately 10 per cent) of Motorola's largely commercial portfolio.[6] The Systems Engineering Group had been created to look for new business concepts for government or commercial markets – a recognition that declining Cold War budgets already had and would continue to undermine the division's long-standing sources of support. Study and assessment of the idea took nearly three years – to articulate more precisely the system's technical aspects, as well as the market context (commercial or governmental) through which it might be developed. Not surprisingly, given the idea's origins in Motorola's government

Figure 1 Engineering notebook, signed by Iridium inventors Bary Bertiger, Kenneth Peterson and Raymond Leopold. (Motorola Museum)

unit, the group first pitched the project to the US military. But as late-Cold War budgets tended firmly downward, the group quickly began to frame the project as a commercial undertaking. The birth and early development of a proposed system for cellular global communications thus coincided with and embodied the historical moment. Iridium's emergence stood as a microcosm of the tangled interconnections among big business, big technology and the changes that roiled politics, international trade and foreign policy during the 1980s and 1990s, with the tearing down of the Berlin Wall in 1989 an iconic and practical watershed. With the end of the Cold War, the turn toward privatisation and markets that gained increasing acceptance during the 1970s and 1980s became, in the 1990s, the dominant political philosophy. From its inception, the Iridium system was invested with the multiple, sometimes conflicting, meanings and connections of this sea change in culture and politics.

During this three-year period of internal assessment, Motorola kept a low public profile on its aspirations for the project. In June 1990, Motorola unveiled Iridium to the public. Reflecting a building enthusiasm (at least in media and political circles in the US and Europe) for the beneficial transformations private markets and communications technologies might stimulate, the roll-out was splashily global. Four press events were held simultaneously – in London, Melbourne, Beijing and New York City, a nod to the project's geographic scope and the realities of generating interest in key financial, media and political circles.[7]

The New York City event was the focal point. The renowned Hayden Planetarium played host, adding a historical echo to the new venture – in 1951 the Hayden hosted the Symposium on Space Travel, a first-of-its-kind event that helped galvanise public interest in space exploration well before the launch of Sputnik in 1957. Iridium seemed a marker of a new phase in the decades-long effort to gain mastery over the space environment. The private sector, through a leading American corporation, one that notably had no tradition of spacecraft or satellite manufacture, was confidently willing to initiate the most expensive business start-up in history to create a unique infrastructure in space. The message: the market was now positioned to join, and perhaps supplant, government in the exploitation of space and, by implication, to bring individuals, as entrepreneurs and consumers, closer to the space experience. More broadly, the venture offered an exclamation point to the possibilities of the market, of an age in which entrepreneurship and technology might subsume the globe, making the control of time and distance a consumer option. These messages quickly gained amplification: within months of the Iridium announcement several other firms announced their plans to provide global telephone and data services.[8]

Technology, corporations and markets stood out as compositional elements of the global milieu of which Iridium was a part. But central to and deeply embedded in this triumvirate was the techno-cultural phenomenon of communications. At the time of Iridium's beginning, the personal computer, the Internet, the World Wide Web, cellular telephones, undersea fibreoptic cables, satellite communication (especially as it related to direct-to-home TV and immediate 'you are there' long-distance news coverage) were all nascent as technologies or as ubiquitous services or commodities. But individually and as a collective development, they had become imbued, through the 1980s and into the 1990s, with rich cultural symbolism – a symbolism that fused technological advances with the possibility of reinvigorated individual liberty and expression.[9]

Figure 2 Overview of communications using the Iridium system. (Iridium Inc.)

A press already enamoured of markets, communications technologies and their possibilities responded to Iridium with enthusiasm. More than 1400 newspapers carried the 1990 announcement – many on the front page. The *New York Times* ran it on its front page with the headline 'Science fiction nears reality: pocket phone for global calls'. In good pop-culture fashion, the announcement, too, found its way into a Johnny Carson monologue and a Batman comic strip. The Beijing event received substantial play in China, running on the evening news. Approximately 250 million Chinese viewers heard parts of the Motorola press release and saw dubbed portions of a promotional video depicting how the satellite communications system would work.[10]

Soon after the press announcement Motorola established Iridium as a separate corporation, a 'start-up' in the parlance of the time, with the parent company controlling the largest single share of the enterprise. Within a few years, more than a dozen investors joined in, representing a diverse sampling of companies and countries around the world – including, prominently, China and the former USSR, the *personae non gratae* of the Cold War years. The price tag for this global venture eventually reached close to $7 billion -- the most expensive privately-financed 'start-up' in contemporary business history. The venture's scope, representation and cost led *Wired* magazine in 1998 to dub the undertaking as the 'united nations of Iridium', a new market-driven reinvention of the state-centred United Nations.[11]

Motorola – through its history and standing as a successful high-technology company – seemed as ready-made as any business for implementing a world-view in which corporations and markets were

Figure 3 Cellular beam pattern created on Earth's surface by the Iridium system. (Iridium Inc.)

central. A Fortune 500 company, Motorola was then the third-largest electronics firm in the US and the largest manufacturer of cellular equipment in the world. It had sales offices around the globe and production facilities in more than 20 countries – including China.

The project's signature technical feature was a constellation of 77 satellites in low-Earth orbit – the '77', the same as the atomic number of the element iridium, and hence the source of the venture's name.[12] The orbiting satellites served as the equivalent of cellular towers, connecting to mobile customers below, using wireless hand-held phones (see Figure 2). As one of the founding engineers noted, the constellation 'bathed the planet in radiation', enabling a completely global phone system – a seeming teleological end point to more than a century of patchwork, geographically-limited terrestrial communications and to the not-fully-global system of satellite communications initiated in the 1960s.[13] A schematic diagram of satellite-created 'cells' on the Earth's surface vividly conveys the technical achievement (Figure 3).

As Iridium got under way, its coverage in the media (primarily print and the newly-emergent domain of the Web) arced from spectacle and promise in 1990 to tragedy in 1999 and 2000 – when Iridium entered bankruptcy protection a mere nine months after its commercial launch in November 1998 and then re-emerged in late 2000 as a much smaller, much less ambitious company, with a new group of investors supplanting Motorola and its pan-national partners as owners. From this vantage, the story seemed to have a beginning, middle and end, and a second chance. It had vision, ambition, risk, luck, failure, a global stage, a cast of thousands, former enemies reconciled and shadowed connections between the military and commercial. Its rise, fall and partial resuscitation neatly bracketed the post-Cold War phenomenon, the boom and bust of communications in the 1990s.

In news accounts the Iridium origins story highlighted the Motorola engineers as exemplars of the inventive spirit and minimised the late-Cold War context of their activity. They sold the idea 'up' the corporate hierarchy over a period of nearly three years, with the newly market-oriented military division overcoming the doubts and resistance of Motorola's much larger and more important (in dollar and sales terms) commercial divisions. The 'little' guys persuaded corporate leadership to make the project a priority, which led to the worldwide announcement already described.

In the first years after the announcement, Motorola and the Iridium 'start-up' overcame a number of hurdles – gaining a series of national and international regulatory approvals for spectrum allocation and permissions to operate, acquiring several billions of dollars in financing from sources around the world, and organising and implementing, by the reckoning of the participants and the press, one of the most complicated technical projects ever attempted. Each of these steps pushed a crucial envelope of global transformation: the shift from government to private market and corporate ownership of communications services. Iridium often was at the vanguard of defining or benefiting from the creation of new legal and regulatory regimes to accommodate this transformation.[14] These challenges and their surmounting by Motorola and Iridium signalled, with exclamation marks, the market-sparked reshaping of the global landscape.

Successes in the political–media world were matched by accomplishments inside the factory. Satellites pulsed off the production line in late 1996 and early 1997 – at peak manufacture a fresh satellite appeared every five days, a radical departure from the prior industry standard of a two- to four-year cycle for producing a single satellite. During 1997 and 1998, rockets launched from Baikonur, Kazakhstan, Taiyuan, China, and Vandenberg Air Force Base, California, began to place tens of satellites into a communications constellation. A 1997 IPO (initial public offering) for common stock helped connect the enterprise to the mania for Wall Street and market wealth. The gateways – the national and regional franchises owned by international investors, sited around the world and responsible for selling iridium to real-live customers – readied for business. A worldwide advertising campaign preceded commercial service, which began in November 1998. But the target markets for the phone – primarily corporate business travellers – did not rush to buy in as expected. A slow-motion sense of collapse – historic, business-school-textbook-for-years-to-come failure – unfolded at real-time speed.[15] Phone and service sales stayed paltry compared to projections – and in a few months the result was financially catastrophic. In August 1999, Iridium filed for bankruptcy, sought to reorganise, but eventually collapsed in late 2000. Motorola planned to de-orbit the entire constellation, bringing the enterprise to a spectacular, eyes-to-the-heavens finale. A new investor edged in to buy the expensive system for pennies on the dollar – $20 million for the $7 billion system.

Iridium's collapse as a business had multiple causes, but revolved around an assumption that proved untenable. Motorola and Iridium anticipated that consumer purchase of the phone service would mirror the uptake of cellular telephones earlier in the 1990s, which displayed a substantial 'S curve' – that is, a rapid takeoff of sales in a short period of time. Bank loans made to Iridium (some of which were guaranteed by Motorola) assumed this analogy to cellphones and required substantial repayments in the first few months after initiation of commercial service. When Iridium sales fell short of the cellphone model, the banks demanded payments that Iridium could not meet, leading to bankruptcy. A mix of internal and external factors undermined the assumption of an 'S curve' model, including: a poorly organised sales effort, underproduction of cellular phones, the cost of individual phones and service contracts, the inefficiency of the gateway sales model, and perhaps above all, the maturation of ground-based cellular phone networks available at lower cost and with international coverage. Iridium's failure quickly became conflated with the 'dotcom' bust, a symbol of overreach and out-sized expectations.

A narrative thread tied this denouement to the project's beginning in the Cold War: the US Department of Defense (DoD) pushed for new ownership in the bankruptcy process and the preservation of the system. With the system's worldwide, almost-anywhere capabilities, the DoD expressed interest in Iridium from its conception, signed a multimillion-dollar contract when the system went commercial in 1998, and, in a mirror image of the commercial Iridium, had its own separate gateway in Hawaii to facilitate communications. Motorola also designed telephones for encrypted communications. The DoD renewed its original contract in 2000 to help new ownership commit to a post-bankruptcy company. In the aftermath of September 11, Iridium (now called Iridium Satellite in its reincarnated form, with all ties to Motorola and the original investors severed) has enjoyed its best financial moments, boosted by an increasing flow of military and other government business, as well as increased use by the media in covering the Afghanistan and Iraq wars.

Culture in and through the artefact

Of course, nearly all artefacts may be threaded into a larger narrative and serve as compact bearers of symbols and cultural preoccupations. Iridium, in this sense, perhaps conveys rich associations by virtue of its timing – as a venture inseparable from a broad reconfiguration of relationships among technology, culture, business and politics. It neatly captures notions of the global, the virtues of markets and the rhetoric of empowerment attached to new communications technologies – as well as concerns about the concentration of power in corporate hands

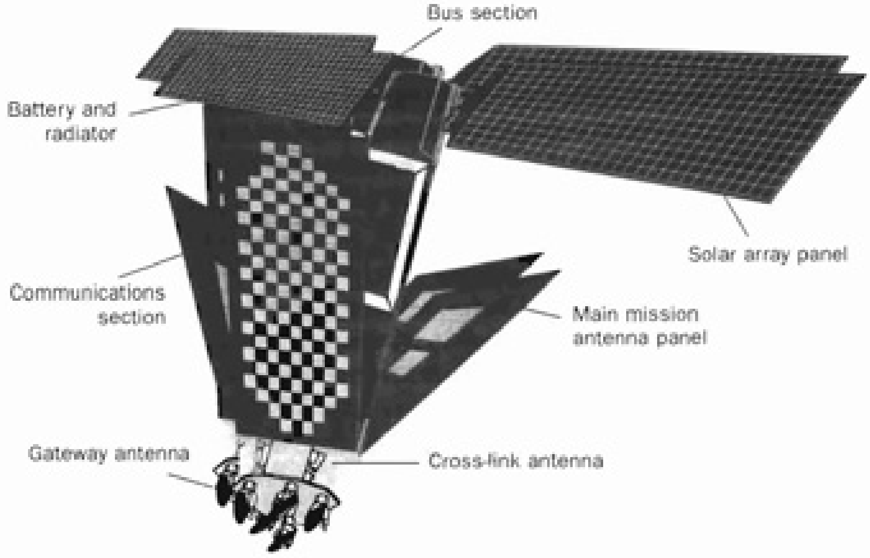


Figure 4 Schematic diagram of Motorola Iridium satellite in its deployed configuration. (Motorola)

and economic inequities on a transnational scale. As technology and artefact, though, the Iridium system – and the satellites, in particular – was more than a vessel carrying a cultural story. The satellites' design, manufacture and organisation embodied in specific ways the milieu of which they were a part.

But as a museum or a curator, how might one see such embodiments – of culture in the artefact and the making of culture through the artefact? A simple 'reading' of the artefact, at most, suggests questions for exploration – for example: Why was the satellite built to this size and configuration? Why was it designed with three types of antenna (phased array, cross-link, and telemetry, tracking and control)? Why do two sides of the spacecraft each sport a large aperture that remains open even in orbit (look closely at Colour plate 9 for the apertures and see Figure 4 for identification of the satellite's main components)? Answers to such questions are bound up in the notions of Iridium as a system and as an expression of 1990s culture. As with any 'big technology', though, pursuing those answers is not straightforward. In the Iridium case, project documents are voluminous and mostly inaccessible – Motorola, as with most companies, judiciously guards its corporate records.[16] The cast of characters often is large and decision-making dispersed across institutions and geographically. Also, the nature of modern corporate and technical communications leans toward the spare (think of PowerPoint briefing slides), obscuring the context in which ideas and choices develop. One partial antidote, used in this study of Iridium, is structured oral history – an approach that is a practical as well as an epistemological strategy. Participants provide a level of meaning unavailable in the written record (even if it was comprehensively available). A cross section of interviews spanning working-level engineers and a variety of managers and different institutions has been used to offer insight into the interconnections among artefact (the material expression of specific choices), system and culture, into the tacit as well as explicit characteristics of the venture.

These interviews have yielded two broad, overlapping frames of meaning for understanding the Iridium satellite as artefact and history. One is the interrelation between design choices (of the satellite and the system) and assumptions about the global. The other centres around the notion of 'manufacturability' – the ideas and techniques that informed project management. The latter concern derived from Iridium's distinctive need to produce and launch tens of satellites over a one- to two-year time frame. In the 30 years prior to Iridium, satellites were craft technologies and typically required several years to produce a single spacecraft. The 'how' of satellite manufacture loomed as a central problem, affecting the relation of design and manufacture, the ways in which Cold War techniques for project management were adapted for market-oriented big technology, as well as the norms and expectations that structured the work of engineers and managers. The NASM's Iridium satellite particularly captures this latter context: it was the first satellite produced at a specially-designed Motorola manufacturing facility in Chandler, Arizona, and served as a test of innovations in 'manufacturability'.

Iridium's design and notions of the global

As Iridium took shape in the late 1980s and early 1990s, the idea and rhetoric of 'globalism' already had gained wide currency.[17] But it was a descriptor that bundled together assumptions, corporate and market practices, and national and international policies that still were contingent, in flux, in the process of codification. Iridium was part of this process, invoking and grappling with the particulars of engineering (in both senses of the term) the global. Two senses of the global pervaded Iridium. In the foreground was that of transnational markets and the day-to-day business activities of transnational corporations. In the background was the global presence of the US government, particularly the military. Motorola saw Iridium as a response to both as categories of global business activity.

As the venture developed it maintained a careful ambiguity on whether Iridium was a global mass-market product (and, thus, as with the Internet, was a communications technology with broad implications for personal and political transformation) or pitched at a more specialised niche.[18] Indeed, Iridium was conceptualised and designed in its technical specifications to serve a very particular class of users – international business travellers, especially those from the US, Europe and Japan. The new levels of international business activity in the 1980s created, in the eyes of Motorola, a substantial and likely increasing number of business officials on the move across the international landscape, predominantly flowing from developed to undeveloped countries, and in need of improved communications options. This insight came out of the international travel experience of those at Motorola who conceptualised Iridium. In the early 1990s, the company had facilities in more than 20 countries and sales offices in tens more – its own needs seemed emblematic of the potential for mobile, wireless communication in a world increasingly defined by the pulse of international business activity.

To satisfy such travellers, the Iridium system would have to meet one seemingly quirky criterion – it would have to enable a voice transmission from inside an automobile as a caller traversed from an international airport into its adjacent city (most such airports were sited outside cities). The goal was to enable a call back to the home office or other site to coordinate global business among relevant staff. The entire technical specification of the Iridium system was designed to meet this scenario. The crucial design element was creating sufficient 'link margin' – that is, radio signals with enough power – to meet this specific, perceived service need.[19] Determining this link margin then determined every other facet of the system – the numbers of satellites, their size, their power, their antenna design, all grounded in a particular construction of how global business practice operated and would operate in the future.[20]

Adhering to this criterion resulted in a substantial redesign of the entire system. As noted above, when the system was announced in 1990 the satellite constellation comprised 77 satellites, arranged as 11 satellites in 7 orbital planes, with near-equidistant spacing, each tracking over the Earth's poles. In 1992, tests on the ground and from aircraft indicated that the initial design did not provide sufficient link margin to meet the baseline criterion – the satellite electronics and cellular antennas did not generate a sufficiently powerful signal. In this version, the satellite buses were hexagonal and the antennas integrated into the surface of the spacecraft. To generate signals of sufficient power the satellites were made larger, reconfigured to a triangular shape, and antenna panels, larger than the originals, were appended to the spacecraft. To keep the project at the same cost, the constellation was reduced in size, from 77 to 66, in a revised arrangement of 6 orbital planes, each with 11 satellites.

Satellite and system design reflected Motorola's sense of the global in other ways. In addition to the antennas used to communicate with Earth-based cellular phones, each satellite also had 'cross-link' antennas, used to communicate with satellites directly in front of or behind a given satellite in an orbital plane or with satellites in adjacent orbital planes. These antennas were integral to a distinguishing technical feature: on-board switching of communications signals – that is, routing of calls through the space system to a specified destination. Iridium, thus, could process calls in two ways: from one Iridium phone to another anywhere on the planet through the constellation (as a 'stand-alone' communications network), or by connecting an Iridium phone call to land-based (line or cellular) systems through a ground station that linked space and land-based networks.

While switching was a common element of land-based telephony, it had not been used in commercial communications satellites.[21] These satellites traditionally had been 'bent pipes' – they served as conduits positioned in geostationary orbit to relay communications from a given point on Earth to another point or region. To make communications satellites as reliable as possible they were designed as simply as possible – that meant no on-board switching capability. Significantly, Iridium's primary competitor in satellite telephony, Globalstar, followed this traditional standard. Satellites in its constellation acted as 'bent pipes', a design choice that required more than 20 ground stations to provide coverage, each of which provided the switching that Iridium performed in orbit. And given the expense of ground stations, Globalstar targeted its service to the most populous land areas, bypassing coverage over less-populated higher latitudes and over the oceans. Globalstar's design and business choices highlight Motorola's distinctive conception of the global as one embracing commercial and military activity over the entire planet.

But the ambition reflected in the Iridium system's design was balanced against the realities of the political landscape in the post-Cold War world. The constellation's on-board switching capability meant that processing calls through the system technically required only one ground station to link the network to land-based networks. Over most of the twentieth century, though, most countries controlled communications, either directly through state-run entities or through designated corporate monopolies (as with AT&T in the US). Iridium (or any communications venture) needed permission to send signals in and out of any national territory – and for a global service this meant the negotiation and arrangement of permissions on an unprecedented scale. Even with the move in the 1980s toward privatisation of communications, states carefully examined granting control over communications within their territories to foreign firms. Thus, as a matter of politics, Motorola and Iridium courted companies and state entities from nations around the world to participate – as investors to spread the financial risk of the project and as owners of gateways. The gateways served as inducements to support the venture. They acted both as technical entities that linked the constellation to ground-based communications and as business units that sold Iridium service in a particular region. In China, for example, such an arrangement was crucial to gain access to this market. The inclusion of 'not technically required' gateways greatly complicated the production of software to operate the system as well as the business structure of Iridium, each complicating the venture's possibility of success.

'Manufacturability': culture in the factory

Recall the artefact-based question posed earlier: why does the spacecraft have apertures that remain open to the space environment in orbit? A narrow, partial answer is straightforward: to allow workers ready, waist-high access to a satellite's interior to affix and test the communications payload during manufacture and checkout. But why does such a seemingly unsurprising objective have import? This and similar design and manufacturing choices in Iridium reflected a broad rethinking of the traditions and procedures for building satellites.

In the US, this tradition, 30 years in the making, developed around state-sponsored big technology. It established particular methods of project management, of the relationship between funding agency and prime contractor, of protocols for manufacture and test, and a variety of other organisational and technological assumptions. As applied to satellite manufacture, this methodology, as noted above, typically resulted in a time frame of several years for producing a single satellite. For Iridium, 'manufacturability', then, was a conceptual position that sought to question, reconfigure and adapt this prior set of practices and assumptions. More importantly, it aimed to take this reinvention and merge it with two overlapping developments of the 1980s: the methods of Japanese manufacture (especially as developed in the automobile industry) and new approaches to achieving high-quality and reliable products.[22] For the latter, Motorola codified and promoted a managerial and statistical technique called Six Sigma that was incorporated into Iridium. This hybridism was central to Iridium and yielded tension as the project applied old and new methods of management, design and manufacture.

The apertures in the spacecraft then were not just apertures. They represented materially a shift from state- to market-sponsored technology as well as a perceived imperative to respond and accommodate a new genre of market, the fluid competitive arena of the global. Motorola, as did other companies, saw these changes as a call to re-examine assumptions on a broad scale – from the organisation of a technical project on an international scale to the behaviour of workers on the factory floor.

From Cold War to post-Cold War: project, system and integration

In 1997, after several years of design and preparations, Motorola began producing Iridium satellites in its Chandler, Arizona, facility. In the parlance of the aerospace industry the factory 'integrated' satellites – a final, material expression of a years-long undertaking. 'Integration' is a term of art in the aerospace industry with deep technical and political meanings – it is the crucial activity of the project, its conceptual and managerial underpinning. As a companion to 'system' (one usually talks of systems integration), it represents a set of ideas, tools, actions that will compose a technology from a myriad of sub-technologies produced at multiple institutions, geographically dispersed and with different sets of expert knowledge and skills.[23] Integration presumes planning and control across space and time – from the initial steps of design to the end stages of manufacture. It is instrumental; each action, step and sub-step all build toward a specific technological end. Through attention to process, integration makes the production of big and complex technologies seem routine, and the remarkable social acts of organisation required seem unremarkable. What becomes 'integrated' thus encompasses institutions, disciplines, people and material things.

During the Cold War, the US military and NASA, wielding the political and financial sway of government purpose and authority, experimented with and advanced new ways of combining technological and social frameworks under the rubrics of systems engineering and the project. Early in the period, the challenges of large-scale project management – of integration – were the focus of substantial creative effort, spurred by the demands of military and NASA programmes. In the 1950s and 1960s, the media covered this innovation with regularity, marvelling at the creation of a new national capability – sometimes expressed through the sometimes optimistic, sometimes ironic question, 'If we can send humans to the Moon, why can't we eradicate poverty or cure cancer or (fill in the blank)?' By the end of the Cold War, the techniques of project management (at least in their government-oriented manifestation) had become commonplace, readily known and applied as needed, at least within the aerospace community and allied industries.

Iridium was deeply connected to this history – through its mode of organisation and through institutions and individuals. A subset of Motorola's Government Electronics Division provided the managerial and engineering expertise for defining, designing and building the system under contract to the Iridium 'start-up' business. This arrangement emulated, with a commercial, self-referential twist, the basic formulation of the Cold War project – a rough separation, at least on paper, between a project and the political and funding environment of which it was a part. But as lead investor in Iridium the corporation, Motorola controlled both sides of the institutional equation. The Motorola group thus exercised powerful influence over development of the entire effort.

In the earliest phase of the project the market-oriented question 'Will it be profitable?' was balanced with the techno-organisational question 'Could it be built?' And the basic resource in answering the latter was knowledge of the techniques and practices for implementing big technology projects – questions of management and process. Iridium connected to this prior experience through two channels. One, noted above, was the project's origins in Motorola's government service division. This division, as with similar divisions in other firms oriented toward military product lines, primarily subsisted on contract. In the case of Motorola, the Department of Defense, National Security Agency and NASA were key patrons and it was the prospect of diminishing government dollars that spurred this Motorola division to contemplate reinventing itself for the commercial world – a recurring and familiar story throughout the Cold War as the availability of contract dollars cycled through highs and lows. The other channel linking Iridium to project tradition was through personnel who joined the project – several of the key people who managed Iridium's system design, manufacturing and cross-institutional coordination and contracts came from the US Air Force as leaders of military projects, a demographic shift of expertise from the state to the market at the end of the Cold War.

But Motorola adapted this legacy in key ways – reflecting intertwined conceptions of markets, the global and the technological. The Cold War project was a creature that sought to coordinate and control geographically-dispersed, heterogeneous activity through the management of information and institutions – through techniques such as centralised control of systems design, configuration management, schedules and, of course, contracts. It was a form and a set of processes designed to coordinate institutional inputs and only secondarily to alter organisational, individual or professional conceptions of work. Iridium, in contrast, saw the values, norms and work of individuals, and in correlation the culture of the firm, as essential sites of action and experimentation.

As a commercial undertaking, though, the project was not a cross-institutional, cross-disciplinary tool to advance the state of technological art or scientific knowledge. Iridium explicitly was conceived to use underlying technologies that had proven their workability – although the system might use such technologies on a new scale (for example, on-satellite switching processors for directing calls around the network) or in new applications (such as phased-array antennas – a crucial technology in establishing cellular communications between the satellites and the Earth's surface – which had only been used in Earth-based applications previously). This was to ensure greater predictability and control over costs and schedule, and thus to reassure potential investors that the project could provide a return on capital. The history of state-sponsored Cold War projects that pushed scientific or technical boundaries proved, as Motorola and others knew, almost always to exceed expected costs and development times.

'Manufacturability': the problem of culture

One approach to gain purchase on the terrain of the 1990s and the adaptation of the Cold War project to an era of global markets is to look at the ways in which the categories of the technical and the cultural were constituted in the Iridium project and the problems and ideas that informed this process. During the 1980s, at Motorola and other firms, an article of faith took hold: that there was a correlation between the internal life of the corporation and the ability to participate in global markets. This concern derived from specific trends and experiences that occurred during the 1970s and 1980s: a shift towards deregulation in trade law and communications policy; the increasing role of transnational companies in shaping global markets; and the Japanese manufacturing challenge in electronics and automobiles – a challenge Motorola directly confronted in its semiconductor business.[24] In the US, the competitive success of Japanese firms gave rise to a simple equation that revolved around the concept of 'quality': Japanese companies produced products of superior quality; that quality derived from cultural factors – inherent in Japanese business methods and in Japanese society; US corporations produced products of lesser quality; thus, US corporations, in the context of transnational markets, had ill-adapted cultures. In anthropological terms, the missing element was a shared system of signifiers and symbols that conceptually and emotionally tied together individuals, practices, corporate goals and international markets.[25] Many large firms saw cultural ill-adaptedness as a problem to be analysed and solved. One result was an eruption of new managerial methodologies that promised remedy – Continuous Quality Management, Total Quality Management, Theory Z and more.[26]

Two features of this intellectual turn should be noted. One, it was not a critique of capitalism, but a purposive effort to insert culturally-grounded methodologies into the basic framework of profit.[27] Two, it identified an explicit relationship between the internal culture of the firm and performance in global, geographically-dispersed markets. Motorola responded to this evolving perspective perhaps more deeply than any other company. In 1986, it articulated a philosophy and set of practices it dubbed Six Sigma, designed to recast corporate culture to meet the changing relationships among markets, technology and business.[28] It conjoined several elements: a commitment to subject to analysis any and all business processes and practices (mantra: 'nothing is sacred'); an emphasis on the use of statistical methods to ground such analyses quantitatively (hence, Six Sigma – to reduce errors to a statistical variance of 3.4:1,000,000); and to train each employee – from the shop floor to managers – to use the method and then charge them to reshape their immediate work environments. In theory, all employees had one beacon: to uncover, and then improve, defects in products and processes, technical and non-technical. The Six Sigma way was a blend of analytical rigour, empowerment ideology and symbolism – the core of a corporate language intended to fuse together business strategy, technical practice and individual behaviour and commitment. Terminology reinforced the notion that individuals and work teams were the foundation of a larger corporate and international market culture; for example, Six Sigma adepts were designated 'black belts' as an analogy with the martial arts and a rhetorical echo of the Japanese challenge.

This interest in and commitment to notions of culture in the corporate setting found expression in another crucial way. In 1989, Motorola established Motorola University as a central component of this endeavour. Its mission was to thoroughly integrate and sustain Six Sigma in the life of the corporation. The university was one, notable instance of a larger trend: over a decade, from the mid-1980s to mid-1990s, more than a thousand corporate universities were created in the US – all of which were a response, in one fashion or another, to the perceived culture problem.[29] Iridium, conceptualised over the period 1987–90, was an inextricable part of this context. Indeed, the perception of the project as globally revolutionary reinforced this notion that a self-reflexive, adaptive corporate culture generated effects that rippled outward across the world stage.

One might view these developments through the long-running discussion beginning with Weber, Veblen, Frederick Taylor and Henry Ford on the relationship among workers, managers, bureaucracies, markets and states, on the striving of modern institutions for rationalisation and efficiency. The difference, perhaps, is that in the 1970s and 1980s many disciplines and social groups began to invoke culture as a descriptive and analytical category.[30] Frederic Jameson, in a seminal 1991 book, observed that for authors committed to the idea of a postmodern condition, culture had become a 'veritable second nature'.[31] By the mid-1980s, Motorola came to a similar point of view – but framed in terms of the technical, organisational and business interests of the corporation. Culture and the rhetoric of culture became a strategic tool to create new ways of corporate life.

In Iridium, this focus on cultural rather than discrete technological problems may seem odd. Iridium was a sprawling technological system, with many 'first' features and problems – ranging from designing a global communications system and optimising its thousands of components to developing software to run customer billing operations that accounted for the telecommunication policy idiosyncrasies of every country in the world. But unlike many of the state-sponsored examples of Cold War big technology, Motorola did not have to overcome a set of critical 'make-or-break' technical problems to realise the end system – systems managers and engineers, as a design strategy, chose only technologies that were well behaved or at least previously tested. The key challenge was management: organising and motivating the many actors involved – Motorola, contractors, subcontractors, and financial and political sites around the world – to build and integrate the system within specific money and time constraints.

In pursuing the project, Motorola viewed this new Six Sigma-based culture as its crucial asset. Most of the leaders of the Iridium project had worked on company defence and intelligence contracts for communications subsystems. They had no commercial experience, no experience in executing large, complex technical systems. Their advantage, they believed, was the Six Sigma way of looking at the world, the value of which the market and competitors had begun to ratify. During this period, Motorola's cellular products and services were dominating the market. Within this context, Iridium project managers had a significant insight: that after more than 30 years of organised effort, spacecraft systems, particularly communications-satellite systems, were well understood. Each new project need not be viewed as an R&D effort, requiring a multi-year process of design, development, tests, manufacture and more tests.[32] The technical and management knowledge associated with state-sponsored big technology could be translated, rationalised and subsumed into the Motorola framework and reconstituted as market-oriented big technology.

Such thinking informed the initial formation of the project. Motorola selected Lockheed and Raytheon as partners in the Iridium project – the former to build spacecraft buses, the latter the spacecraft phased-array antennas. Motorola performed system design and overall integration, thereby controlling the project, and also contributed the communications payload, their in-house technical forte. One part of the price of admission was a commitment to accept and thoroughly adopt Motorola's idea of project culture, based on Six Sigma. Over the period 1991–95, the company took a series of formal and informal steps to indoctrinate contractors and subcontractors – to create a lived commitment to a way of thinking, working and interacting. The goal was to identify and realign assumptions, processes and social boundaries to harmonise the established knowledge on developing space-based systems with market requirements for meeting schedule and cost estimates, product reliability and global scope. An outline of the results of this process can be seen in a series of graphics prepared by project designers as they described and promoted their methodology to contractors, potential investors and professional and academic audiences.

The notion of the virtual factory (Figure 5) encapsulated the Motorola approach. The trope of virtual-ness was not meant to convey that these heterogeneous, geographically-dispersed institutions were linked via contract, or in a computer-age sense, via information umbilici. Rather the project's likeness to a factory was that all its elements – from Chandler, Arizona, to Baikonur, Kazakhstan, and Taiyuan, China, shared a common set of technical practices. These practices, employee behaviours and commitments, and a market-oriented view of the world, constituted a project way of life. The virtual-ness of the factory was that this way of life could

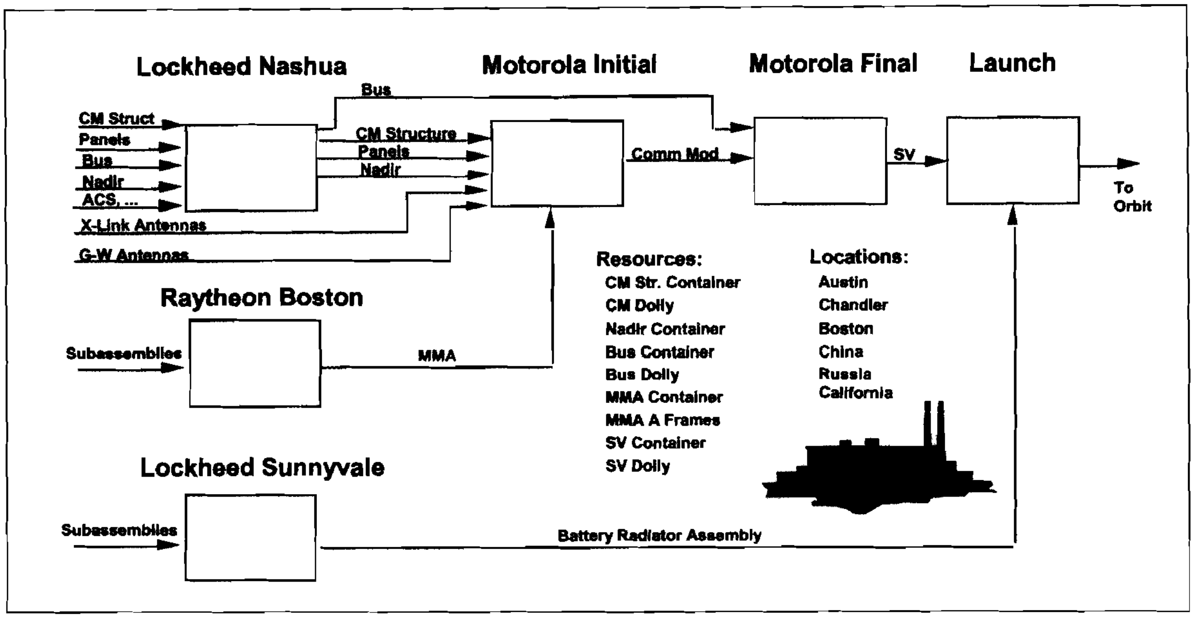
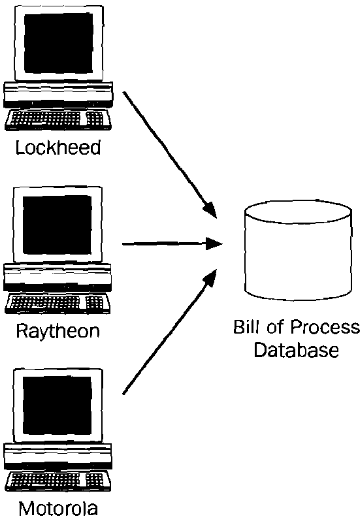


Figure 5 The virtual factory. (Andrew Feller)

be transported and replicated, albeit with difficulty, to disparate institutions and cultural sites. The trope of the factory performed work too. It strengthened the idea that the project established new social boundaries, drawing in and redirecting elements of other institutions, into a new, substantive community.

The emphasis on process – that is project actions analysed, broken down into constituents, reconfigured for the market ends of cost, schedule and quality, a cycle iterated again and again – was the key departure from state-oriented project management (see Figure 6, which shows the core idea of this approach, a complete database of thousands of discrete process steps, and Figure 7, an 'exploded' view of one process activity). And it was through this emphasis on process that the individual – from low-level subsystem tester to project manager – became fundamentally integrated into the project culture.[33] In Figure 6, note that individual names (in project terms 'ownership') are attached to each process step.

The attention to process and culture was a mutually supporting enterprise. The process emphasis allowed a connection between a set of technical practices and a symbolic frame of shared values and commitments – a frame that served to define work life at local sites and connect it to the instrumental transcendent ethic of the 1990s market: that you could do well and do good, make a profit and spur a liberal democratic remaking of the world. Motorola, and other firms, tailored the concept of culture to meet the perceived challenges of global markets, a strategy that only intensified with the collapse of the Soviet Union. In Iridium, this concept of culture associated with Six Sigma led to a new methodology of project execution, a new



IRIDIUM SPACE VEHICLE BILL OF PROCESS

Sequence Level	Process Name	Cycle Time	Location	Person - Process
5790	Pack and Prep Battery	4	Sunnyvale	Kevin Bilger
6000	LAUNCH SITE HEADER PAGE	0	Launch Site	JORDAN
6057	Transport SV/Dispenser to Launch Complex	8	Launch Site	Jeff Finan
1280	Thermal Cycle	52	Boston	Paul Babbit
5070	SV Liveness Test	6	Chandler	Hyrie Bysal
6020	SV Confidence Test	4	Launch Site	John McBride
1210	Attach Velcro Strips to Panel	0.7	Boston	Richard Russo
1040	Dispense Adhesive & Assemble Patches	.575	Boston	Richard Russo
1060	Assemble and Bond T/R Modules	.57	Boston	Richard Russo
1230	**Lay Thermal Blanket Over Panel Back**	**0.2**	**Boston**	**Richard Russo**
229.1	COM MODULE, Propulsion System-Weld	5.75	Austin	Machine Operator
239.1	BUS MODULE, Propulsion System-Weld	4.95	Austin	Machine Operator
1050	Attach Patch Hold Down Fixture	0.2	Boston	Richard Russo
1230	Lay Thermal Blanket Over Panel Back	0.2	Boston	Richard Russo
5800	Ship From Sunnyvale	168	Sunnyvale	Jordan Snyder
6035	Receive Flight Battery Radiator Assembly	2	Launch Site	John McBride
1260	Element Test	18	Boston	Paul Babbit
1070	Bond and Assemble Drive Modules	1.4	Boston	Richard Russo
1090	Bond and Assemble Power Regulators	3	Boston	Richard Russo
243	BUS MODULE - Propulsion System Purge and Seal	0.91	Austin	Assembler
1290	Calibration Verify	16	Boston	Paul Babbit
6120	Charge Batteries	10	Launch Site	John McBride
1330	Clean Panel and Pack	1.0	Boston	Richard Russo
4110	CS Functional Test - Station 8	48	Chandler	Mike Monteith
5030	Propellant Line Connection	7	Chandler	Hyrie Bysal
5031	Propellant Line Connection - Welding	7	Chandler	Hyrie Bysal
1130	Attach R.F. Cables and Flex's to T/R modules	7.0	Boston	Richard Russo
1140	Assemble P/R Flex	0.5	Boston	Richard Russo
1100	Cure & Remove Fixture	168	Boston	Richard Russo
2780	Ship CM Structure to Comm Space	1	Austin	John Tiernann
1900	Ship MMA to Comm Space	24	Boston	Paul Babbit
220	NADIR-Receiving	3.26	Austin	Certified Assemble

Figure 6 Schematic diagram of a 'bill of process' database. (Andrew Feller; document redrawn)

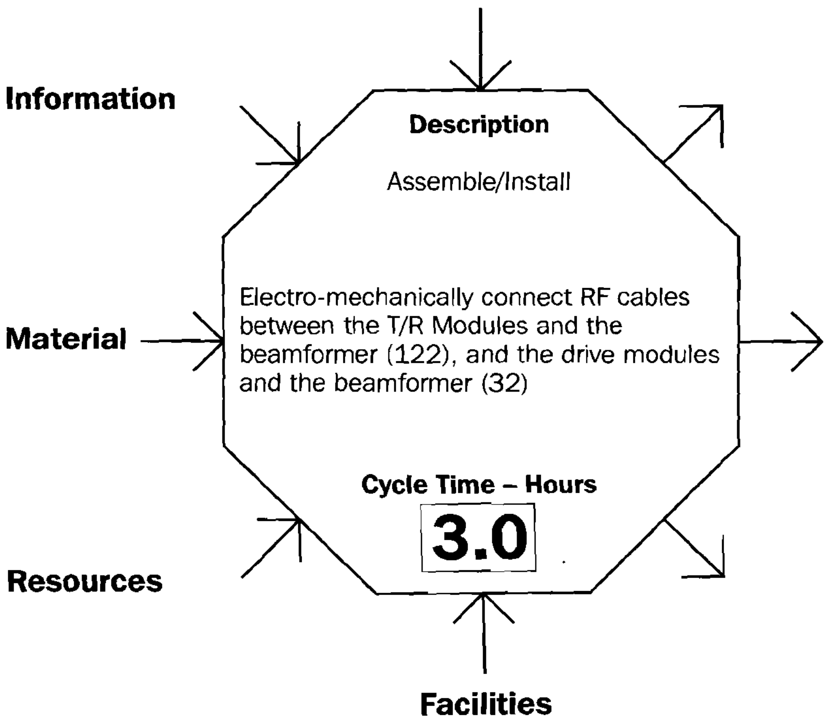


Figure 7 Schematic diagram of a 'process icon'. (Andrew Feller; document redrawn)

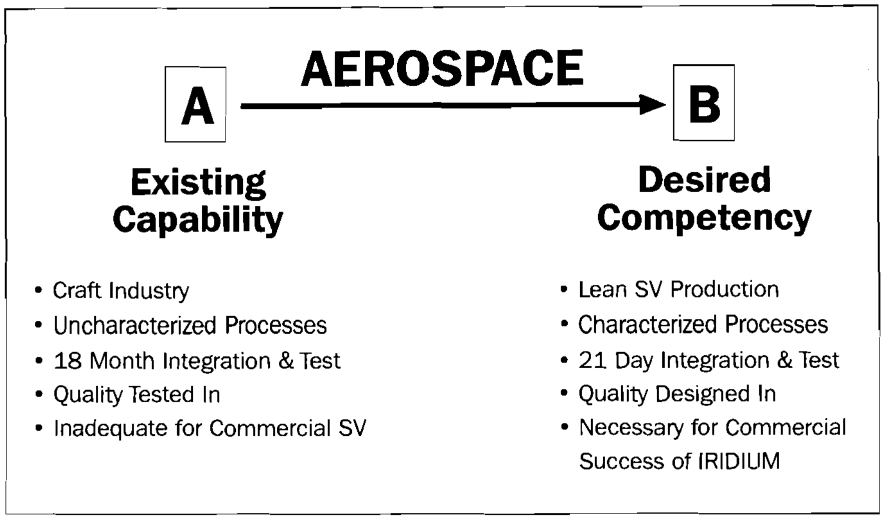


Figure 8 Leading an industry transformation. (Andrew Feller; document redrawn)

means to create large-scale technology. While this had commercial ramifications, it also exemplified new configurations of military–industry collaboration. The project had deep and ongoing relationships with the US military from its inception, and the military was one of first and best customers of this satellite telephone system. Motorola's methodology for achieving quality provided a clear alternative to more than 40 years of military practice and opened up new possibilities for defining the military–corporate relationship in the age of the market. (For a stripped-down Motorola view of this connection see Figure 8.) Lastly, the move to culture signalled the continuing elision and shifting over the decades of the Cold War and after of a variety of conceptual and social boundaries, including those relating to academia and industry, and markets and states. Through these elisions and shifts, history and business have come to an odd mirror-image juncture: they now are methodological companions, both actively seeking to comprehend the manifold interplay of technology and culture.

Conclusion

Part of the argument of this essay is not new – indeed in the context of the science and technology studies literature it is well worn: that culture and technology are produced in concert.[34] Iridium as technological system and as satellite artefact may be offered up as exemplars, creations distinctive of the mixing of markets, globalism, corporations, big technology and military interests at the end of the Cold War. While co-production may be viewed as utilitarian and metaphorically evocative for history, it is problematic for the museum. The multi-causal perspective and the attempt to explain cultural and technological change within a layered narrative simply are an ill fit for the concision required of exhibitions and for the progress-oriented stories with which museum administrators and visitors seem most comfortable. The challenges of explaining big technologies only intensify this history and museum mismatch – they expand the scale and complexity of the narrative.

In turn, the artefact, the museum's trump, seems to offer, at least for space-age technologies, a modest return for history. Though it is rarely evidence in explaining historical change, the artefact, in addition to providing a culturally-situated marker of visitor values, perhaps best serves as a concrete pointer – a call to look more closely at the institutional and technical matrix from which it was produced, to see it as real-world untidy material and conceptual problem. As in the case of the Iridium satellite, the artefact, in the technical choices it presents, may point to specific lines of inquiry that open the world behind the object. Perhaps in this way the museum can find common cause with history as a discipline.

Notes and references

1 For a discussion of the relationship of artefacts to the history of technology see, for example, Corn, J, 'Tools, technologies, and contexts: interpreting the history of American technics', in Leon, W and Rosenweig, R (eds), *History Museums in the United States: A Critical Assessment* (Urbana/Chicago, IL: University of Illinois Press, 1989), pp237–61.

2 For a more in-depth discussion of artefacts and historiography, see the introduction to this volume.

3 As one marker of the near totality of this shift, see Jasanoff, S, *et al.* (eds), *Handbook of Science and Technology Studies* (Thousands Oaks, CA: Sage Publications, 1995).

4 See for example Hughes, T, *Human-Built World: How to Think About Technology and Culture* (Chicago, IL/London: University of Chicago Press, 2004); Winner, L, *The Whale and the Reactor: A Search for Limits in an Age of High Technology* (Chicago, IL/London: University of Chicago Press, 1986); and Beck, U, *Risk Society: Towards a New Modernity*, trans. Ritter, M (London: Sage Publications, 1992).

5 In 1998, *Aviation Week and Space Technology*, in recognition of their role as inventors of Iridium, awarded the three its Laureates Award.

6 For an overview of Motorola in the 1980s and 1990s see Steinbock, D, *Wireless Horizon: Strategy and Competition in the World Wide Mobile Marketplace* (New York: Amacom, 2003), Chap. 8.

7 Bradshear, K, 'Science fiction nears reality: pocket phone for global calls', *New York Times* (26 June 1990), ppA1, D7

8 As costs and regulatory complications arose, all but one of these efforts gradually folded their tents over the 1990s. The one remaining competitor was Globalstar, backed by Loral, an aerospace industry stalwart. Globalstar succeeded in financing and building its system, but always trailed along behind Iridium's vanguard. Globalstar, like Iridium, went through bankruptcy before achieving some measure of stability.

9 A useful overview of literature on the idea of an information society, the multiple meanings attached to the concept of communications, and their relation to capitalism and postmodernism is Webster, F, *Theories of the Information Society* (London: Routledge, 1995).

10 These events in China are related in Gercenstein, M, Oral History Interview, Iridium Oral History Project, NASM. Gercenstein was Iridium's representative in China at the time of the press announcement.

11 Bennahum, D, 'The United Nations of Iridium', *Wired*, 6/10 (October 1998), pp134–8, 194–201. By 1998 the investors, in addition to Motorola, included Bakrie Group of Companies (Indonesia); Saudi Binladin Group (Saudi Arabia) – an entity that gained notoriety after September 2001 through its familial connection to Osama bin Laden; Vebacom (Germany); Inepar SA (Brazil); BCE Mobile Communications (Canada); Ilapeca (Venezuela); Kyocera Corporation (Japan); Industrial Development Bank of India; Krunichev State Research and Production Center (Russia); SK Telecom (Korea); Telecom Italia; Sprint (USA); Lockheed Martin (USA); Raytheon (USA); UCOM (Thailand); Pacific Electric Wire & Cable Company (Taiwan); and China Aerospace International Holdings.

12 As design of the system evolved over the next few years the number of satellites in the constellation was reduced to 66 – the atomic number of the element dysprosium. The relation of this design change to Motorola's conception of the global is discussed below.

13 Motorola and Iridium couched this claim as 'nearly' global coverage. The signal could not penetrate buildings. Structures in dense urban areas and canopies of trees might shade, obstruct or diminish satellite signals.

14 Although not covered in this paper, the creation of new national and international regulatory regimes friendly to communications was a central part of the Iridium story and of international trade in the 1990s. The Federal Communications Commission, analogous regulatory bodies in other countries and the International Telecommunications Union played crucial roles in facilitating Iridium through revised frameworks for allocating spectrum and providing guidelines for international communications. Similarly important were new regimes of international trade contained in the World Trade Organization, which paid particular attention to communications.

15 Iridium already has become the subject of business-school case studies. See, for example, McCormack, A, and Herman, K, 'The rise and fall of Iridium', Report 9-601-040, Harvard Business School, 2001.

16 The author has, however, had extensive access to Iridium corporate records. These contain a broad range of communications from Motorola, including those relating to design, manufacture and project management.

17 The literature relating to the global is vast. Crucial for the discussion here are Albrow, M, *The Global Age* (Stanford, CA: Stanford University Press, 1997) and Robertson, R, *Globalization: Social Theory and Global Culture* (London: Sage Publications, 1992).

18 Or more precisely, Iridium's rhetoric was populist and its business plan aimed for the 'cream' of the market. From the beginning, estimates for phone prices ranged from $2000 to $3000 and per-minute charges were around $3 – both above cellular standards of the early to mid-1990s.

19 Link margin was dependent on two factors: the power of the signal generated from the satellite and the efficiency of a ground antenna in receiving the signal. The critical variable was the strength of signal generated by the satellite.

20 On the clear connection between system design and perceptions of global business practice, see Hillis, D, Oral History Interview, Iridium History Project, NASM. Hillis was a pivotal figure in Iridium. As the project was initiated, he was a key manager in Motorola's defence unit and was the person most responsible for shepherding the idea from embryonic stage to support by Motorola management. He then served as head of the project and was instrumental in shaping the project's engineering and organisational culture.

21 Switching technology was tested on NASA's Advanced Communications Technology Satellite (ACTS) launched in the late 1980s. ACTS was the last in a long-running series of NASA experimental spacecraft intended to assist the communications-satellite industry in evaluating new technologies. Significantly, Motorola received the contract to develop the switching technology for ACTS, an experience that directly influenced the company's decision to use the technology in Iridium. Concurrently, the military began to develop switching technology for use in its MILSTAR satellites that began deployment in the late 1980s.

22 The Japanese manufacturing challenge, especially in automobiles, gave rise to a number of responses and studies. MIT conducted a seminal analysis that had a deep impact on US manufacturers, published as Womack, J P, *et al.*, *The Machine That Changed the World* (New York: Rawson Associates, 1990).

23 It is important to distinguish Hughes's original notion of 'system' from the Cold War concepts of the project and integration. While there are important similarities, there is a key difference. System as developed in Hughes's seminal work *Networks of Power* was an accretive process – an effort extending over time in which the articulation and build-up of a technological complex was contingent on advocates securing markets and, as needed, political accommodations. As a product of entrepreneurship, markets and capitalism, system started from the bottom and worked up – its end point was never pre-determined or foreordained. In the Second World War and the Cold War, this formula largely was reversed. The large-scale system, in concept, existed from the start. The political authority and funding capability of the state enabled the translation of concept into something concrete – first as an active project organisational structure, a system of contracts and perhaps eventually a technological complex. The material and political dynamics of the project and integration thus are fundamentally different from Hughes's original concept of system. Hughes himself seems not to have highlighted this difference – in his work on Cold War subjects, system is approached in the same way as in pre-Second World War examples. On the early Hughes see Hughes, T P, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: Johns Hopkins University Press, 1983); for treatment of Cold War systems see Hughes, T P and Hughes, A C (eds), *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After* (Cambridge, MA: MIT Press, 2000).

24 On the origins and development of the deregulation and markets-over-governments movement, see Yergin, D and Stanislaw, J, *The Commanding Heights: The Battle Between Government and the Marketplace That Is Remaking the Modern World* (New York: Simon & Schuster, 1998).

25 For an analytical discussion of definitions and characteristics of culture see Williams, R, *Sociology of Culture* (Chicago, IL: University of Chicago Press, 1981).

26 A useful overview of these developments is Waring, S P, *Taylorism Transformed: Scientific Management Theory Since 1945* (Chapel Hill, NC: University of North Carolina Press, 1991). For a critique of this movement see Jackson, B, *Management Gurus and Management Fashion: A Dramatistic Inquiry* (London: Routledge, 2001)

27 At the same time, a different but related business work culture was emerging: the egalitarian commune-esque style of computer start-ups. Explicit concepts of culture were important here, too, but rationalisation of process was not one of its primary characteristics. For an in-the-trenches example of this culture see Kidder, T, *The Soul of a New Machine* (Boston, MA: Little, Brown, 1981).

28 Over the 1990s, Six Sigma spread to other large firms such as General Electric and became the preferred tool for corporate cultural reinvention, spawning a substantial 'how-to' literature. The bible is: Pande, P S, *et al.*, *The Six Sigma Way: How GE, Motorola, and Other Top Companies Are Honing Their Performance* (New York: McGraw-Hill, 2000).

29 For an overview of this trend from a policy perspective see Cunningham, S, *et al.*, *The Business of Borderless Education* (Canberra: Commonwealth of Australia, Department of Education, Youth, and Training, 2000).

30 For a comic, often polemical and sometimes accurate account of the relationship between academic cultural studies and business uses of culture, see Frank, T, *One Market Under God: Extreme Capitalism, Market Populism, and the End of Economic Democracy* (New York: Doubleday, 2000), Chap. 8.

31 Jameson, F, *Postmodernism, or, the Cultural Logic of Late Capitalism* (Durham, NC: Duke University Press, 1991)

32 A good account of the history of government-sponsored project management is Johnson, S B, *The Secret of Apollo: Systems Management in American and European Space Programs*

(Baltimore, MD: Johns Hopkins University Press, 2002).

33 The importance of process as a strategy in recent business is developed in Pisano, G, *The Development Factory: Unlocking the Promise of Process Innovation* (Boston, MA: Harvard University Press, 1997). As implied above, the attention to process derived principally from the Japanese model of 'lean production'. For an account of the application of lean production outside Japan, see Delbridge, R, *Life on the Line in Contemporary Manufacturing: The Workplace Experience of Lean Production and the 'Japanese' Model* (Oxford/New York: Oxford University Press, 1998).

34 For a useful overview of the strengths and shortcomings of the historiography of science and technology studies, see Pestre, D, 'Thirty years of science studies: knowledge, society and the political', *History and Technology*, 20 (2004), pp351–69.