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Terra Firma Medical Systems (A)

Introduction

On a brisk autumn day in late April, Marvin Keats strode along the crystal blue waters of Wellington Harbour and up a steep hill toward a modern office building with a gleaming glass facade, where he was due to meet with his boss. The building was home to the global headquarters of Terra Firma Medical Systems, along with several other rapidly growing New Zealand companies. Keats had just flown in from Singapore, where he served as the Director of IT & Operations for the Asia Pacific region. His boss, Stephanie Clark, was the company's Chief Operating Officer (COO).

Clark had summoned Keats to discuss the disastrous network failure that crippled Terra Firma's main data center the previous week. While the Wellington-based corporate IT staff had already brought the company's critical information systems back online and begun restoring access to the remaining applications and services, the experience had convinced Clark that after years of underinvestment, major new capital expenditures were needed to modernize the company's IT infrastructure and address the problems that had brought thousands of employees to a near-standstill for several days. She was counting on Keats, a relatively new arrival at the company but a seasoned IT manager with experience at several multinational firms, for an infusion of fresh thinking and hard-headed analysis.

Time was short and the stakes were high. The Board of Directors was scheduled to meet in early May to approve the annual budget, so Clark had only a matter of days to convince the company's eccentric co-CEOs to support her request for what she guessed would be a multi-year commitment totaling hundreds of millions of dollars. Moreover, while Terra Firma had enjoyed a decade of rapid and profitable growth, the company faced substantial uncertainty in all of its major product markets due to technological innovation, competitive pressure, and regulatory changes that were sweeping the health care sector in the United States and Europe.

Given this uncertain environment, Keats was worried about simply throwing money at the problem. He wanted to use his meeting with Clark to propose a different approach, which he had asked his team in Singapore to develop in detail over the last 24 hours.

He paused to catch his breath and check his BlackBerry. He was relieved to see an email from his team with the documents he needed for the meeting. Eager to hear the team's ideas and ask them a few questions, he glanced through the documents briefly and dialed the Singapore office.

Assistant Professor C. Jason Woodard prepared this case for the 2010 SMU APEX Global Business IT Challenge, with generous input from Narayan Ramasubbu, Kevin Steppe, Laurence Liew, Wong Yuet Nan, Lee Hing Yan, Eric Clemons, and two anonymous sources who served as inspiration for characters in the case. The company featured in the case is a fictional composite based on publicly available information. Many other facts have been altered or disguised for educational purposes. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

Industry Overview: Diagnostic Medical Imaging Equipment

Terra Firma was a leading supplier of advanced sensors for medical imaging devices such as X-ray machines and computed tomography (CT) scanners. Its products were primarily sold to large medical equipment vendors such as General Electric (GE), Philips, Siemens, Hitachi and Toshiba, which in turn integrated them into imaging systems that were sold to hospitals, outpatient imaging clinics, doctor's offices, and research laboratories. In addition, the company had recently introduced a line of filmless dental and veterinary X-ray systems, which were sold through a global network of independent distributors and a fast-growing direct sales force. Terra Firma also provided technical support and integration services for imaging systems and developed software for visualizing, analyzing, and storing medical images.

The total size of the medical imaging market was estimated at US$50 billion in 2009, and forecast to grow by about 6% annually for the next five years.[1] In developed countries, this growth was driven by the increasingly routine use of magnetic resonance imaging (MRI) and CT scans in the diagnosis and treatment of major illnesses such as heart disease, cancer, and neurological disorders. In the developing world, the use of X-ray and ultrasound imaging was on the rise due to expanded access to affordable and reliable equipment, especially in rural areas. Although the escalating cost of health care was a worldwide concern, private insurers and national health systems continued to reimburse providers of imaging services at economically attractive rates due to the perception that these services helped to increase the quality of care and reduce overall costs through early intervention, increased diagnostic accuracy, and avoidance of unnecessary medical procedures.

The medical imaging industry was broadly segmented into equipment (80%) and consumables (20%). Most of the revenues in the consumables segment came from chemical substances such as contrast agents and radiopharmaceuticals, which were used to help scanners detect structures or processes related to a particular patient's health problem. Terra Firma participated exclusively in the equipment segment, which was in turn segmented by the type of imaging provided (CT, MRI, X-ray, nuclear medicine, and ultrasound). Exhibit 1 describes these product segments in more detail.

Sophisticated imaging systems required multi-million dollar capital outlays to procure and install, as well as ongoing investments to operate (particularly in hiring and training qualified staff). As medical devices — some capable of delivering lethal doses of radiation if improperly calibrated or operated — these systems were also subject to extensive health and safety regulations, which varied widely by country. The competitive playing field was thus tilted in favor of a handful of multinational firms whose health care divisions could deliver end-to-end solutions to customers across all major geographical markets. These firms, the largest of which were GE and Siemens, accounted for the majority of sales to end customers.

While the large equipment vendors engaged in substantial in-house product development and manufacturing, they also relied on partners and suppliers for critical components. Some of these components, such as X-ray tubes, were based on mature technologies; suppliers of these components competed mainly on cost and quality of service. Other components, including most of the sensors supplied by Terra Firma, were highly specialized and required extensive investments in research and development (R&D) to bring to market. Although these investments were risky,

[1] Espicom Business Intelligence (2009), "The World Medical Markets Fact Book," p. 89. The remainder of this section draws on a report by The Freedonia Group (2009), "Freedonia Focus on Medical Imaging Products."

successful innovators enjoyed high profit margins due to intellectual property protection, limited availability of substitutes, and strong demand for state-of-the art imaging capabilities at the top medical centers worldwide.

Two major trends had shaped the medical imaging industry over the past decade: [2]

- First, the resolution and speed of scanning devices had improved dramatically. For example, the time required for a full-body CT scan had dropped from about 20 minutes to 30 seconds, while the size of the images produced had increased from thousands of pixels to millions. These gains made it feasible to combine data from multiple scans into vivid 3D images, and in some cases to update these images dynamically to produce "movies" (4D images) showing changes over time.

- Second, hybrid scanners that combined two or more imaging techniques were becoming increasingly common. For example, PET/CT scanners were used to show both biological activity (e.g., abnormal growth associated with a cancerous tumor) and its precise location in the patient's body. These hybrid devices made it possible to overcome the limitations of each imaging technique, while avoiding the need to stitch together images taken on different machines at different times, which was often time-consuming and error-prone.

Imaging devices were also being combined with other kinds of medical equipment, such as linear accelerators used for treating cancer with high-energy radiation. These combined systems enabled new techniques, such as image-guided radiation therapy (IGRT), that allowed doctors to see and adjust their treatment plans in real time, giving them finer-grained control and allowing more precisely targeted treatments.

Overall, it was an exciting time in the industry. Nonetheless, competitive and regulatory pressures loomed for both large equipment vendors like GE and smaller suppliers like Terra Firma. Large vendors worried about the backlash against rising health care costs — especially in the US, which accounted for almost half of the global market for medical equipment, but also in Europe and Japan, which were under pressure from aging populations and anemic economic growth. Vendors of imaging equipment were bracing themselves for new regulations intended to curb excessive use of imaging tests by physicians, and lower payments to imaging service providers by public and private medical insurers.[3]

Smaller suppliers might also be affected by these measures, albeit indirectly. A more pressing concern for many, however, was their over-dependence on the large vendors for the majority of their revenues. While these vendors generally treated their suppliers well — often engaging in strategic partnerships to jointly develop new technologies or market new product lines — suppliers often found themselves competing with the vendors' internal product development organizations, which in many cases had similar capabilities and could leverage the much larger R&D investments of their corporate parents.

[2] G. Spekowius and T. Wendler (2009), "Medical Imaging," in H.-J. Bullinger, ed., *Technology Guide: Principles – Applications – Trends*, Springer. For more detailed information, see G. Spekowius and T. Wendler, eds. (2006), *Advances in Healthcare Technology*, Springer.

[3] M. Mitka (2005), "Costly Surge in Diagnostic Imaging Spurs Debate," *Journal of the American Medical Association* 293(6), pp. 665–667.

Company Overview: Terra Firma's Unlikely Success Story

The company that became Terra Firma Medical Systems was founded in 1992 by the brothers Godfrey and Allan Frost. The Frost brothers started the company, which they originally named Terra Firma Technologies, to commercialize their dissertation research on medical applications of amorphous silicon sensor arrays. Godfrey had recently earned his Ph.D. in electrical engineering from the Victoria Institute of Advanced Studies (VIAS), an obscure but elite research center nestled in the hills behind Wellington, New Zealand. Allan, who was three years younger than Godfrey, earned his Ph.D. in biophysics at VIAS a year later and joined the company full-time in 1993.

The company's initial efforts were focused on developing high-resolution flat-panel detectors for X-ray imaging. Their approach, which was also taken by research groups in the US and Japan, was to use thin-film transistors (TFTs) — the same technology used in active matrix liquid crystal displays, which were becoming widely adopted in notebook computers — to create large digital detectors with millions of individual sensor elements (pixels). Unlike existing digital detectors based on charge-coupled devices (CCDs, the technology used in digital cameras), even the company's first TFT prototypes yielded images with quality comparable to traditional film-based X-rays.

The main factor responsible for this improvement in quality was the size of the detector. Whereas a typical CCD detector was roughly the size of a fingernail, the Frost brothers' first TFT detectors were as large as an A4 sheet of paper. Their size allowed them to be much more sensitive than CCD detectors with the same number of pixels, and eliminated the need for lenses to focus the X-ray image onto the smaller detector. (This also reduced optical distortion, further improving image quality.) Although production costs were initially high, the Frosts' design was technically simpler than comparable CCD-based designs, which they believed would ultimately lead to more compact detectors that could be produced at lower cost.

Their first commercial success came in 1998, when Siemens agreed to purchase up to 10,000 of Terra Firma's detectors for its new line of high-end X-ray imaging systems. The five-year deal provided enough financial stability to secure construction loans for a full-scale production facility, as well as the cash flow needed to hire additional staff without raising new capital. Determined to make the most of their good fortune, the Frost brothers led a rapid expansion into other types of medical imaging sensors, including X-ray detectors for CT scanners and gamma ray detectors for PET and SPECT systems. (MRI and ultrasound imaging worked on very different physical principles, so the company chose not to enter these markets.)

By 2003, the company was generating almost NZ$1 billion in annual revenue.[4] Now formally known as Terra Firma Medical Systems, the company had opened sales and service offices in the US, UK, Germany, Japan, Australia and Singapore, as well as a manufacturing facility in Penang, Malaysia, that was jointly owned and operated with Intel. Still eager to expand but no longer able to fund the company's growth internally, the Frost brothers reluctantly brought in their first outside investors to help them build up their international footprint and fill out their product lines. Only a select group of wealthy New Zealanders were invited to participate. The group was rumored to include the owner of the country's largest sheep farm, an award-winning film director, an actor known for his temper and fondness of rugby, and the inventor of bungee jumping.

[4] In April 2010, one New Zealand Dollar was worth approximately S$0.98 or US$0.72.

Despite their inexperience in the corporate world (or perhaps to offset it), the investors insisted on hiring a professional management team. While the Frost brothers were equally adamant about retaining their positions as co-CEOs, they agreed to the appointment of Stephanie Clark as Vice President of IT & Operations and COO.

Clark's colleagues described her as a "force of nature." They marveled at her ability to work through the smallest details of an operational problem — often trapping subordinates in her conference room late into the night — without losing sight of the company's broader goals. She instilled a relentless focus on planning and execution, which often clashed with the company's engineering culture. While they shared her passion for high-quality designs, Terra Firma's product development staff tended to doubt the wisdom of trying to perfect these designs on a fixed schedule or budget.

These differences came to a head in 2005 during an 18-month effort to develop a filmless X-ray system for dental and veterinary applications. Clark saw a huge market opportunity in these low-end segments, where current film-based imaging equipment was relatively cheap but the total cost of ownership was much higher due to the costs of procuring, storing, and retrieving X-ray film. Successfully pursuing opportunities to displace film in this segment would require strict cost discipline and the delivery of a complete "turnkey" system, breaking with the company's traditional role as a component supplier. Her colleague Richard Weisen, then the Vice President of Product Engineering, agreed that the plan made good business sense but was reluctant to divert resources from more technically challenging projects to work on essential but mundane parts of the system like lead shielding and the power supply.

After nearly a year of missed deadlines and cost overruns, Clark conceded the battle to bring the product engineering staff into line, but persuaded the Frosts and the Board of Directors to buy the assets of a defunct Australian X-ray machine manufacturer and set up a new division to rebuild its products around Terra Firma's sensors. The head of this new Digital Imaging Systems division was empowered to hire his own direct sales force and forge relationships with distributors in Australia and Southeast Asia. The new DigiRayZ product line was finally launched in 2007, and quickly grew to become a NZ$345 million business.

At the same time, Terra Firma began to invest more heavily in software development. Back in 2004, at the urging of one of its new investors, the company hired a small team of programmers with experience in graphical rendering who had recently worked on the special effects for a series of blockbuster films. The team put their skills to use in developing new techniques for 3D and 4D imaging. While a number of "pure-play" software companies were already working in this area, the Frosts felt they had an advantage due to their deep knowledge of both detector physics and the relevant biological processes. Their first product was released a year later, laying the foundation for another new division called Imaging Software Products. Although this division was still the company's smallest business unit in 2009, it was by far the fastest growing.

Company veterans noted that Terra Firma had finally started to feel like a mature enterprise over the past few years. Field offices now operated on four continents, with manufacturing taking place in New Zealand, Australia, and Malaysia. (Terra Firma bought out Intel's stake in the Penang plant in 2008.) The organization had also evolved toward a classic multi-divisional form. To complete this process, Weisen was tapped to lead a newly formed Sensor Components division, which included his existing engineering groups (TFT Flat Panel Detectors and Advanced Imaging Subsystems) and their associated sales and marketing teams. A separate customer support organization was formed to manage the company's technical support contracts and system integration services, which had grown into healthy profit centers in their own right.

By the end of 2009, annual revenue exceeded NZ$2.5 billion, and the company employed over 5,200 full-time staff. Exhibit 2 summarizes the company's recent financial performance.

The Frosts were fiercely competitive board game players with a reputation for shrewd tactics. One of their favorite games was Risk. While they lamented the fact that New Zealand lacked its own territory on the board, both brothers unfailingly pursued the same approach: to control Australasia first and sweep outward from there to achieve world domination. When asked by a reporter if this was an appropriate metaphor for their business strategy, Allan replied with a full-throated cackle.

Information Technology & Operations at Terra Firma

At Terra Firma, as in many companies, information technology was so deeply embedded into the fabric of organizational life that it was generally taken for granted except when it failed — and thanks to the efforts of the company's 180 full-time IT staff, it didn't fail very often. The spectacular network crash of April 2010 was a rare exception. Although the disruption it caused was frustrating and costly, it served as a wake-up call to the company's senior management that perhaps they should pay more attention to their IT investments.

As a company founded during the golden age of personal computers, before the commercialization of the Internet ushered in a new era of network-centric computing, Terra Firma's IT organization evolved in an organic and decentralized way. Microsoft Windows 3.1, arguably the product that cemented Microsoft's control over the desktop PC market for the next 15 years, was released in April 1992, just as Godfrey Frost was putting the finishing touches on his dissertation. Every employee who joined the company was given a choice of a desktop or portable computer running Windows and Novell NetWare (for file and printer sharing). At the time, computationally intensive engineering applications still required UNIX workstations, so the product development organization also supported a variety of Sun Microsystems and Silicon Graphics machines. Meanwhile, the fledgling accounting department installed an IBM AS/400 server to run software by J.D. Edwards.[5] While much of this hardware and software was upgraded over the next decade, most of the core enterprise applications remained in place.

Prior to Stephanie Clark's arrival in 2003, Terra Firma lacked a corporate-level IT department. The majority of the company's IT staff were co-located with the product engineering teams and reported to Weisen (a trusted deputy of the Frost brothers), while the rest were scattered across the various functional organizations they supported. Clark had spent the majority of her career helping manufacturing companies realize the benefits of IT and factory automation technologies, so she recognized the importance of aligning IT and operations. She therefore argued against creating a separate Chief Information Officer (CIO) position, advocating instead for the IT function to be consolidated under her position along with the company's other operational activities such as

[5] The J.D. Edwards software, known as World, was an enterprise resource planning (ERP) package similar to SAP but targeted at small and medium businesses. J.D. Edwards was acquired by PeopleSoft in 2003, which was in turn acquired by Oracle in 2004.

accounting, human resources, procurement, and manufacturing. While Weisen was reluctant to transfer staff out of his organization, Clark assured him that they would continue to provide dedicated support for the company's research, development, and testing activities. This arrangement proved workable, and had persisted with minor adjustments ever since.

Exhibit 3 illustrates the structure of Clark's IT & Operations organization in 2010. Her operations departments had a matrix reporting structure, with global managers for each function as well as cross-functional managers like Marvin Keats for each region. (The headquarters area was managed as its own region, which included the rest of Australia and New Zealand.) Clark also established a set of Business-IT Solutions teams to work with the four product and service divisions plus the Corporate Administration group, which included corporate finance, legal and regulatory affairs, and strategy. These teams were responsible for gathering requirements from their respective business customers, developing appropriate solutions (e.g., a new application or enhancements to an existing system), working with the business sponsors to secure funding, and liaising with other parts of the IT & Operations organization to deliver each solution on time and on budget. Most of the technical work was done by a separate Corporate Application Development group, which included teams that focused on IT architecture, enterprise applications (e.g., customization of J.D. Edwards for global use), and applications for internal business customers (e.g., a web-based order fulfillment system for the Imaging Software Products division).

Terra Firma's NZ$150 million annual IT budget was allocated by an IT Steering Committee chaired by Clark. The committee's membership included representatives from each division as well as the major functional units at the corporate level, and most decisions were made by consensus. Exhibit 4 provides a breakdown of the 2010 budget, which was developed by the committee in 2009.

As in many corporate IT organizations, funding was allocated in three main ways:

- Basic services like email, telephone, network connectivity, and PC support were funded on a cost recovery basis through "taxes" levied on each department or division in the company according to its headcount.

- Services that supported corporate-wide functions, such as payroll processing and financial reporting, were funded through annual budget requests prepared by Clark's organization. These requests were also used to fund strategic initiatives and exploratory projects. Recent examples of the latter included feasibility studies on the use of desktop videoconferencing and instant messaging software to reduce the cost of communicating with the field offices.

- Finally, services that primarily benefited a single business unit were funded directly by these units through internal transfers at rates agreed upon by the committee. These services included application development and deployment, purchasing and customization of commercial software, and maintenance of dedicated computing infrastructure. Business units were free to procure these services from outside vendors, but protocol dictated that the committee be consulted first, and Clark's organization typically played a project management role in supervising external service providers.

In an effort to stay current with the best practices for IT governance,[6] the Steering Committee's role had expanded in the last few years to include decisions about IT architecture, infrastructure, and the prioritization of business needs. One result of this expanded mandate was a set of architectural standards for new application development, along with a documented process for deploying and managing applications hosted on corporate IT infrastructure. This process is illustrated in Exhibit 5.

Although the new standards were expected to help simplify Terra Firma's IT infrastructure over time, the vast majority of the company's applications and systems were deployed before the standards came into effect. By one count, Clark's organization was supporting over 200 different applications, fewer than 10% of which adhered to the new standards. Pessimists complained that even these standards were sure to change in the future, turning today's shining examples of compliance into tomorrow's burdensome legacy applications.

Given this reality, Clark's IT infrastructure team had resigned themselves to supporting a messy, heterogeneous mix of hardware and software for the indefinite future. Exhibit 6 describes some of the company's key IT applications. Exhibit 7 provides a high-level view of the company's network infrastructure, which connected its four sites in the Wellington area to its overseas manufacturing facilities and field offices. Exhibit 8 provides a deployment view showing the physical locations of some of the applications listed in Exhibit 6. Finally, Exhibits 9 and 10 illustrate some of the more important collaboration and data flow relationships in Terra Firma's IT architecture.

Despite the complexity of Terra Firma's corporate IT environment, it seemed to operate smoothly (with only occasional hiccups) until an engineer in the Advanced Imaging Subsystems group called the help desk in mid-April to report that he couldn't access his email. This was the last call received by the help desk that day, as the line was shortly cut off by the failure of the main VOIP[7] switch that handled telephone service for the company's HQ-area facilities. Minutes later, support staff at the main data center reached Clark on her mobile phone to tell her that connectivity to both overseas manufacturing plants had been disrupted, and that several applications had crashed due to network timeout errors. Fearing a denial-of-service attack, Clark contacted Terra Firma's main Internet service provider to see if they had observed a spike in incoming network traffic. They had not.

It took another 18 hours and the assistance of several outside experts to establish the proximate cause of the disruption, which was a router that had failed after being flooded with connection request packets, triggering a chain reaction leading to the failure of both the primary and secondary network switches in the main data center. In a turn of events eerily reminiscent of the disaster that occurred at a Boston-area hospital group in 2002,[8] the ultimate cause was discovered to be a new engineering application that was by all indications fully compliant with the new architectural standards, but had apparently never been tested in a production environment.

The situation got worse as the data center staff began the process of bringing the company's critical information systems back online. They discovered a host of new problems, including missing log files, corrupted database tables, and inconsistent application data. While it turned out that no

[6] See, for example, P. Weill and J. W. Ross (2004), *IT Governance: How Top Performers Manage Decision Rights for Superior Results*, Harvard Business School Press.
[7] Voice over Internet Protocol; see http://en.wikipedia.org/wiki/Voice_over_Internet_Protocol.
[8] S. Berinato (2003), "Halamka on Beth Israel's Health-Care IT Disaster," *CIO*, 15 February, http://www.cio.com/article/31701.

serious data loss had occurred, correcting these problems would require weeks of tedious effort performing manual recovery procedures.

Once the recovery process was well underway, Clark began to think about the larger lessons to be learned from the experience. She called Marvin Keats in Singapore to ask for his candid assessment. She was exasperated. “I thought we were prepared,” she lamented. “We spent millions of dollars on fault-tolerance, redundancy, failover – you name it. We had a disaster recovery plan. We tested as much as we could without taking the whole company offline for days at a time. Why did the whole thing blow up so badly?”

Keats assured her that as far as he could tell, her team in Wellington had done everything that could reasonably have been expected of them. He pointed out, however, that Terra Firma’s level of IT investment had lagged industry benchmarks for years, several people with unique technical knowledge had recently left the company, and despite the best efforts of the Steering Committee to impose some discipline on the company’s application development and deployment processes, powerful executives like Weisen still managed to force through exceptions and shortcuts for projects they deemed sufficiently urgent.

Moreover, Keats continued, the network crash was only an acute symptom of more chronic problems with the use of information technology at Terra Firma. IT accounted for over 40% of the company’s capital expenditures, yet most of it either went to replace existing equipment or scale up existing systems — neither of which yielded much of a return on investment in terms of cost savings or business value. It still took too long to get a new application deployed, or even a new sales representative set up with a laptop and an account on the company’s customer relationship management (CRM) system. And the brightest people in the IT & Operations organization were leaving because they were bored — they respected Clark’s professional management style, but longed for new and exciting challenges.

Clark concurred grimly and asked Keats to fly to Wellington the next day to discuss solutions.

Marvin Keats: Feet on the Ground, Head in the Cloud

As Director of IT & Operations for the Asia Pacific region, Keats was responsible for ensuring the smooth operation of Terra Firma’s business activities at the company’s field offices in Mumbai, Bangkok, Singapore, Taipei, Hong Kong, Shanghai, and Tochigi, Japan, as well as the manufacturing plant in Penang, Malaysia. Although he sometimes thought of himself as a glorified office manager (and often not even so glorified), the systems and processes he supported were responsible for over half of the company’s annual production output and almost a third of its revenue.

Keats joined Terra Firma in early 2008. Spurred by strong demand for the company’s new DigiRayZ line of X-ray systems, a dozen field offices had opened in the previous year alone. The situation was chaotic, to say the least. Keats’s mandate was to straighten things out in the Asia Pacific region, developing a robust set of business processes supported by applications and infrastructure that could be scaled up and replicated across the EMEA and NALA regions.

Keats brought an unusual background to the job. Although he held numerous certifications — including Microsoft Certified Systems Engineer (MSCE), Certified Information Systems Auditor (CISA), and ITIL Service Manager — his core IT skills were entirely self-taught. A UK native, he joined Digital Equipment Corporation (DEC) as a technical support engineer at the age of 18. He was a quick study, with a gift for explaining complex ideas in clear and simple language. These qualities helped him jump from a support position into a consulting role, where he developed a reputation as a skilled project manager. Over the next two decades he served numerous clients in a variety of industries, including banking, automotive, petroleum, and professional services. Some of these engagements extended over several years, allowing him to become deeply embedded in his clients' organizations — to the point that his clients became colleagues, and he hardly noticed when DEC merged with Compaq in 1998 and Compaq merged with Hewlett Packard in 2002.

By 2004, Keats was ready for a change. Taking advantage of a generous program offered by the Singapore government to attract high-technology entrepreneurs, he set up an independent consulting firm in Singapore and moved to the tropical island city-state from Berlin, where he had been serving as an IT architect for a large global manufacturer. He decided to focus his efforts on helping clients take advantage of new technologies for shared-service computing such as software as a service (SaaS), utility computing, and grid computing. Singapore had recently launched an ambitious National Grid project[9] to develop the country's capabilities in these areas, and Keats became an active participant in the professional community that coalesced around these efforts.

Like many business–IT professionals, Keats had read and debated Nicholas Carr's controversial Harvard Business Review article that boldly claimed "IT doesn't matter,"[10] as well as its sequel that heralded "the end of corporate computing."[11] And like many of his colleagues, he took offense at Carr's argument that the strategic value of IT had diminished to the point where "IT management should, frankly, become boring" (2003, p. 49). But he agreed with Carr's view that, like electric power a century ago, "information technology … is beginning an inexorable shift from being an asset that companies own in the form of computers, software and myriad related components to being a service that they purchase from utility providers" (2005, p. 67).[12]

This view was shared by many IT vendors, who saw big business opportunities in providing IT as a service, with potentially lucrative recurring revenue streams, rather than simply selling hardware and software on a one-time basis. In fact, a distinct but related trend toward "service-oriented architecture" (SOA) had been under way for several years already. SOA and its associated tools and technologies made it easier to create modular applications whose business-related components could be decoupled from the hardware and software infrastructure that supported them.[13] While most enterprises were still using SOA internally rather than across firms, another set of related technologies known as "Web services" enabled applications created by different firms (e.g., Google Maps, Facebook and Flickr) to interoperate with each other and be composed into new applications by independent developers (e.g., the TripIt travel planning site).[14]

[9] See the Singapore National Grid web site, http://www.ngp.org.sg/.
[10] N. Carr (2003), "IT Doesn't Matter," *Harvard Business Review*, May, pp. 41–49.
[11] N. Carr (2005), "The End of Corporate Computing," *Sloan Management Review* 46(3), pp. 67–73.
[12] This argument is developed further in N. Carr (2008), *The Big Switch: Rewiring the World, from Edison to Google*, W. W. Norton.
[13] For definitions and examples of SOA, see http://msdn.microsoft.com/en-us/library/aa480021.aspx and http://www.ibm.com/software/solutions/soa/.
[14] For a comprehensive discussion of Web services architecture, see http://www.w3.org/TR/ws-arch/.

These technology trends, which could be viewed broadly as a shift toward more loosely coupled systems,[15] were essential to the viability of utility-like business models. After all, if every home appliance required a different kind of electricity (e.g., 120 vs. 240 volts, 50 vs. 60 hertz, alternating vs. direct current), it would be expensive and inefficient to supply it from a central grid. Worse still, if these appliances "cared" how this electricity was produced (e.g., from coal, nuclear or hydroelectric power), multiple grids would be needed even if the voltage, frequency, and type of current could be converted efficiently at the point of consumption. This was roughly the situation for IT until the early 2000s, as Keats and his colleagues were well aware. The recurring question they faced was how fast things were changing — which technologies were ready for "prime time," and for what purposes?

Fueled by a seemingly insatiable need to label abstract concepts with catchy buzzwords, the IT industry soon attached a new one to the cluster of ideas swirling around in this space. In mid-2006, Google CEO Eric Schmidt described an "emergent new model" he called "cloud computing," which referred to the common convention of using a "cloud" icon in system architecture diagrams to illustrate the parts of a network (often the Internet) that were assumed to be present without needing to know their detailed structure.[16] A year later, IBM and Google announced a US$30 million initiative to fund research on cloud computing technologies and applications.[17]

Keats became an enthusiastic proponent of cloud computing, which resonated strongly with the ideas he was already pursuing in his consulting work. But he was also a committed pragmatist. Never content to push the latest technology for its own sake, he wanted to help his clients distinguish the reality from the hype, and apply new technologies only when and where he was confident they could be harnessed to create real business value. He also knew that while different organizations often faced similar problems, the appropriate solutions depended on the specific details of the organization and its business environment. One size definitely did not fit all. Furthermore, a good solution was not merely a "technological fix" but rather a combination of changes to business processes, information systems, and human factors — the way people were organized and managed — that all needed to be aligned to bring about a desired outcome.

By coincidence, Keats met the manager of Terra Firma's new Singapore office at a social function in late 2007. He saw a rare chance to put his ideas into practice on a larger scale, and was excited both by the freedom he would have to implement them in the Asia Pacific region, and by the prospect of having a global impact on the company if he succeeded. After a short but intense conversation with Clark, both were convinced he was a good fit. Clark allowed him to keep his newly formed consulting business and join the company as an advisory contractor, but he wore his Terra Firma "hat" on a nearly full-time basis and operated within the company like a regular employee.

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[15] The concept of a loosely coupled system is by no means specific to information technology. See, e.g., K. Weick (1976), "Educational Organizations as Loosely Coupled Systems," *Administrative Science Quarterly* 21(1), pp. 1–19.

[16] "Conversation with Eric Schmidt hosted by Danny Sullivan," 9 August 2006, http://www.google.com/press/podium/ses2006.html.

[17] S. Lohr (2007), "Google and I.B.M. Join in 'Cloud Computing' Research," *The New York Times*, 8 October, http://www.nytimes.com/2007/10/08/technology/08cloud.html.

Frustration and False Starts in 2008–2009

Much to Keats's disappointment, the last two years had afforded little opportunity to realize his ambitions on the cloud computing front. Reflecting on where the time had gone, he recalled a series of major projects, each of which was urgent and important at the time but in retrospect seemed to lead him away from his goals rather than closer to fulfilling them:

- He spent most of the first six months establishing a basic set of infrastructure services across the field offices, including a secure virtual private network (VPN) that supported email, voice communication, file sharing, and web-based access to corporate applications like payroll and travel expense reimbursement.

  He would have preferred to outsource most of this infrastructure to a full-service provider like BT Global Services or Tata Communications, instead of installing hardware at each office and linking them together through a patchwork of contracts with local telecommunications companies. But he did not have the luxury of a clean slate. With four field offices already operating in his region and three more due to open within a year, he felt that it would have been prohibitively complex and expensive to undo the existing arrangements, and he was wary of making dramatic changes too soon.

- The rest of 2008 was devoted to rolling out CRM software to the Asia Pacific sales force. Prior to 2007, Terra Firma did not use CRM software because most of its sales were to a small number of large medical equipment vendors, and these relationships were managed by dedicated teams based out of the company's field offices in the US, Germany, and Japan. After launching the new DigiRayZ line and expanding its direct sales force, the company adopted Oracle CRM (based on technology acquired from Siebel Systems in 2005) because it offered integration with its J.D. Edwards accounting software.

  Again, given a clean slate he might have chosen a hosted offering like Salesforce.com or Microsoft Dynamics CRM Online (or even Oracle's own CRM On Demand offering), but in this case it was important to be consistent with the corporate standard, at least initially.

- Much of 2009 was consumed by a major effort to improve coordination with the Penang factory after taking over full control from Intel the previous year. The main goal of the joint venture had been to benefit from Intel's vast expertise in semiconductor fabrication techniques to reduce the production cost and improve the quality of Terra Firma's sensors. (Intel was interested in gaining experience with thin-film deposition of amorphous silicon, the particular technique used by Terra Firma, because it was also used to produce solar cells. But despite its growing interest in "green IT," Intel decided not to enter this market.) This focus on cost and quality was expected to intensify even further in the years ahead.

  Engineers at the plant had amassed hundreds of terabytes of production and testing data, and were generating more at the rate of several tens of gigabytes a day. A number of Weisen's product development teams had requested access to the data to optimize their new sensor designs. They also wanted live video links from Wellington to Penang.

  The video links were easy to set up once Weisen agreed to pay for Polycom videoconferencing equipment and ISDN connectivity. The data sharing issue was still unresolved a year later, however. In fact, the new engineering application which caused the network crash was part of an effort to set up a large-scale distributed filesystem between Penang and Wellington, which would have allowed both sides to work with the production data in a seamless way.

These challenges were by no means unique to the Asia Pacific region. Keats had been told, for example, that the developers in the Imaging Software Products division were eager to take advantage of the Beowulf computing cluster run by the Sensor Components division, but had been stymied by network issues as well as difficulties in managing the different kinds of workloads generated by the two groups. The problems were exacerbated by the fact that the divisions were physically separate, with the sensor division located in the company's old headquarters building in the Kelburn neighborhood of Wellington, while the software division was based in the Miramar neighborhood, near the original software team's former employer.

Problems and Opportunities in April 2010

Within an hour of Clark's call to discuss the Wellington network failure, Keats had assembled his team of business analysts in a conference room overlooking the Singapore River. They were young, energetic, and creative; he had hired them not for their industry experience, but for their ability to rapidly understand complex problems and develop innovative solutions through rigorous analysis. He needed one now — or more precisely, 24 hours from now.

Although Keats wanted to help Clark address the root causes of the crash, he knew she wasn't interested in either a detailed technical analysis of the crash itself (which she could get from her own headquarters staff) or a generic prescription for improving the way IT was managed at Terra Firma (which she was quite capable of formulating herself). Instead he sensed an opportunity to advance the agenda he had joined the company to pursue, namely to help Terra Firma transition its IT infrastructure and applications to take advantage of the cloud computing paradigm.

"I think the crash has a silver lining," he told his team, "and it's the cloud."

"Cloud computing means a lot of different things to different people," Keats said, "but when I think about the kinds of decisions we have to make at Terra Firma, this is how I see them." On the whiteboard, he drew a 2-by-2 matrix:

Deployment Environment

System Layer	**Internal**	**External**
Applications		
Infrastructure		

The vertical axis, he explained, separates cloud infrastructure from cloud-based applications. The horizontal axis separates services that are deployed internally (on "private clouds") from those deployed externally (on "public clouds").

"At the infrastructure layer, private clouds are natural extensions of existing technologies for improving the efficiency of network-based corporate IT infrastructure — like server virtualization, which large enterprises have been doing for years." He mentioned ISF from Platform Computing, Moab from Adaptive Computing, Eucalyptus Enterprise Cloud, Citrix Xen, and VMware vCloud as products to watch in this space. "With public clouds like Amazon EC2 and Windows Azure," he continued, "you're talking about putting your applications on someone else's infrastructure entirely. Often the barriers to that are organizational rather than technical — and you have to think carefully about when it might make sense from a financial point of view."

"At the application layer, if you're using SOA — as our new architectural standards require — you're well on the way to deploying them on a private cloud once you set up the infrastructure." He mentioned GigaSpaces XAP and Google AppScale as software platforms that were designed to host cloud-ready applications in a private environment. "Public cloud applications evolved from what people used to call Application Service Providers (ASPs) until that term went out of fashion and got replaced by SaaS and Web services." He noted that public cloud platforms like Google Apps and Force.com had attracted thousands of developers, and predicted that hosted application offerings like NetSuite and Microsoft Online Services would soon start to gain traction in the market.

He instructed the team to think carefully about which parts of Terra Firma's IT environment were ripe for transitioning to what type of cloud computing model, if any, and to give him a realistic timeframe that distinguishes between the short term (a year or less), medium term (next 2–3 years), and long term (next 5–10 years).

"Don't just give me an answer," he directed. "Think about the tradeoffs, think about priorities, think about how we sell this to Clark and what she'll need to do to sell it to the rest of the company. Tell me how this is going to affect our key processes, and what our systems are going to look like when we're done. Tell me what we need in terms of resources — not just dollars, but people and skills — and tell me about the risks. Not Chicken Little stuff — terrorist attacks, that sort of thing — but things we should really be worried about if we go down this path, and what we can do to increase the odds of success."

"By the way," he said, "I think there could be a strategic business play here, too. Our products generate a ton of data — tens or hundreds of terabytes a day, maybe petabytes within a few years. Analyzing it is computationally intensive, especially for things like 3D and 4D rendering. I'm just thinking out loud — don't get distracted from the main problem, which is what do we do for our own use within the company. But if you come up with any ideas along these lines, don't hold back."

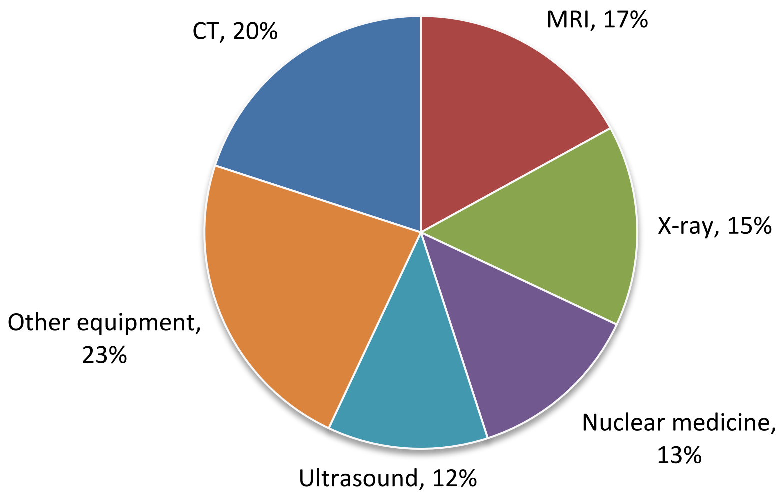
He asked the team to prepare a presentation for him to pitch to Clark, along with a set of supporting deliverables — just a page each. There was no time for more, either for the team to create or for him to explain to Clark during his meeting. He told them to practice the presentation as if they were meeting with Clark themselves. He wished them luck, and left the office to pack his bags for the night flight to Auckland, which would put him in Wellington early the following afternoon.

The Call to Singapore

Judging by his first glance at the documents on his BlackBerry, Keats was pleased at what his team had managed to produce in such a short time. He hoped it would be enough to convince Clark that she needed not just to avoid another data center disaster, but to thoroughly revitalize IT at Terra Firma and position her organization as a strategic partner for the company's business divisions.

As the phone rang and he waited for the team to pick up his call in the conference room back in Singapore, he momentarily glanced up at the sky. He could have sworn he saw a kiwi gliding across the harbor, its distinctive beak leading the way. He rubbed his eyes in disbelief, then chuckled to himself. "Well then," he thought, "if kiwis can fly, surely Terra Firma can find its way to the cloud!"

Exhibit 1: Medical Imaging Equipment Product Segmentation



Computed Tomography (CT)

CT is an *in vivo* diagnostic technique that employs digital geometry to create three-dimensional anatomical images from several two-dimensional X-rays taken around a single rotating axis. Commercially available since the early 1980s, CT has evolved into the preferred diagnostic test for abdominal aortic aneurysm, intracranial hemorrhaging, kidney stones, pneumonia, and more recently, cardiac imaging and cancer detection and treatment. Newer equipment includes multi-detector CT scanners, which can scan the entire body of blunt trauma patients to detect internal injuries; CT/PET hybrid equipment, which is an effective oncology tool for tumor detection; and single-photon emission computed tomography (SPECT)/CT hybrid equipment, which is effective for oncology (e.g., prostate cancer), bone scans, cardiology and diabetes applications.

Magnetic Resonance Imaging (MRI)

MRI enables the viewing of internal anatomy by exposing the body to an electromagnetic field. Technological advances in MRI systems have improved both performance capabilities and patient comfort. High-field scanners, which offer greatly enhanced image detail, are expanding applications in the detection of breast, cardiovascular, musculoskeletal and neurological disorders, and the detection of joint disease. Newer models include the intra-operative MRI (iMRI) mobile, image-guided scanner used for surgery. The latest innovations to reach the market are high field, open-sided scanners that offer enhanced anatomical images and shorter testing times; and larger-bore platforms for obese or claustrophobic patients.

Medical X-rays

X-ray equipment is used to perform initial diagnostic screens on patients with orthopedic injuries, infections, inflammations, tumors, and several other hard and soft tissue abnormalities. Medical X-rays include conventional (i.e., film-based), computed radiography (CR) and digital radiography (DR) systems. CR and DR systems are replacing film-based types because of their ability to meet high-volume needs, reduce the number of retakes, provide high image quality and be integrated into digital diagnostic imaging record-keeping systems. Specialized applications include the diagnosis of dental problems, breast cancer (mammography) and arterial diseases (angiography).

Nuclear Medicine (NM)

NM is a molecular imaging technique that captures and visualizes metabolic functions in the body to detect and analyze various disease states. A majority of NM procedures are cardiovascular in nature. Other uses include bone, brain, thyroid and tumor imaging. Gamma cameras form the core of all nuclear medicine systems, including conventional and newer SPECT configurations. In recent years, the NM community has contended with shortages of a key radiopharmaceutical, technetium-99m, needed for NM procedures, due to unstable foreign supplies.

Ultrasound

Ultrasound's advantages over alternative *in vivo* testing technologies include non-invasive application, non-radiation emission, lower cost per procedure, and the near immediate presentation of live imaging results. The technique is well-suited to the examination of muscle and soft tissue and effectively delineates the interfaces between fluid-filled and solid spaces within the body. Newer ultrasound systems on the market include those that offer quality and color contrast and imaging, over-time comparison views, wireless options, compactness and portability.

Other Equipment

Positron emission tomography (PET) equipment accounted for about a third of demand in this category and set the fastest pace of growth among all medical imaging products, or 18% per year in the 2003-2008 period. PET systems (i.e., PET-only and PET/CT hybrid systems) mainly derive their demand from applications in cancer and cardiology. PET/CT systems create high quality spatial visualizations of internal anatomical structures and present precise virtual images of metabolic activity at targeted *in vivo* sites. Other imaging equipment in this sub-segment includes radiographic fluoroscopy (RF) and miscellaneous small-volume equipment such as dental X-ray, and picture archiving and communication systems (PACS) and radiology information systems (RIS), which can transmit images via the Internet or facility network for remote viewing.

Source: The Freedonia Group. (Market share data adapted by casewriter.)

Exhibit 2: Selected Financial Information for Terra Firma Medical Systems

FY	2005	2006	2007	2008	2009
Revenues					
Components and subsystems					
Flat panel X-ray detectors	762	848	935	1,011	1,083
Other CT/PET/SPECT detectors	325	401	473	549	624
Software and services					
Technical support contracts	175	197	220	243	264
System integration services	59	84	103	126	151
Packaged software products	10	16	27	46	79
Integrated imaging systems					
DigiRayZ product line			48	129	345
Total revenues	1,331	1,546	1,806	2,104	2,546
Expenses					
Cost of revenues	759	897	1,066	1,262	1,553
Research and development	133	139	144	147	153
Selling, general and administrative	226	263	289	337	382
Total expenses	1,118	1,299	1,499	1,746	2,088
EBITDA	213	247	307	358	458
Depreciation and amortization	(40)	(46)	(54)	(63)	(76)
Net interest expense	(16)	(23)	(33)	(42)	(51)
Taxes on earnings	(64)	(72)	(86)	(97)	(128)
Net income	93	106	134	156	203
Beginning cash balance	326	384	517	305	294
Ending cash balance	384	517	305	294	533
Number of employees	3,216	3,692	4,226	4,751	5,213

Note: Units in millions of New Zealand dollars.

Exhibit 3: Terra Firma's IT & Operations Organizational Chart

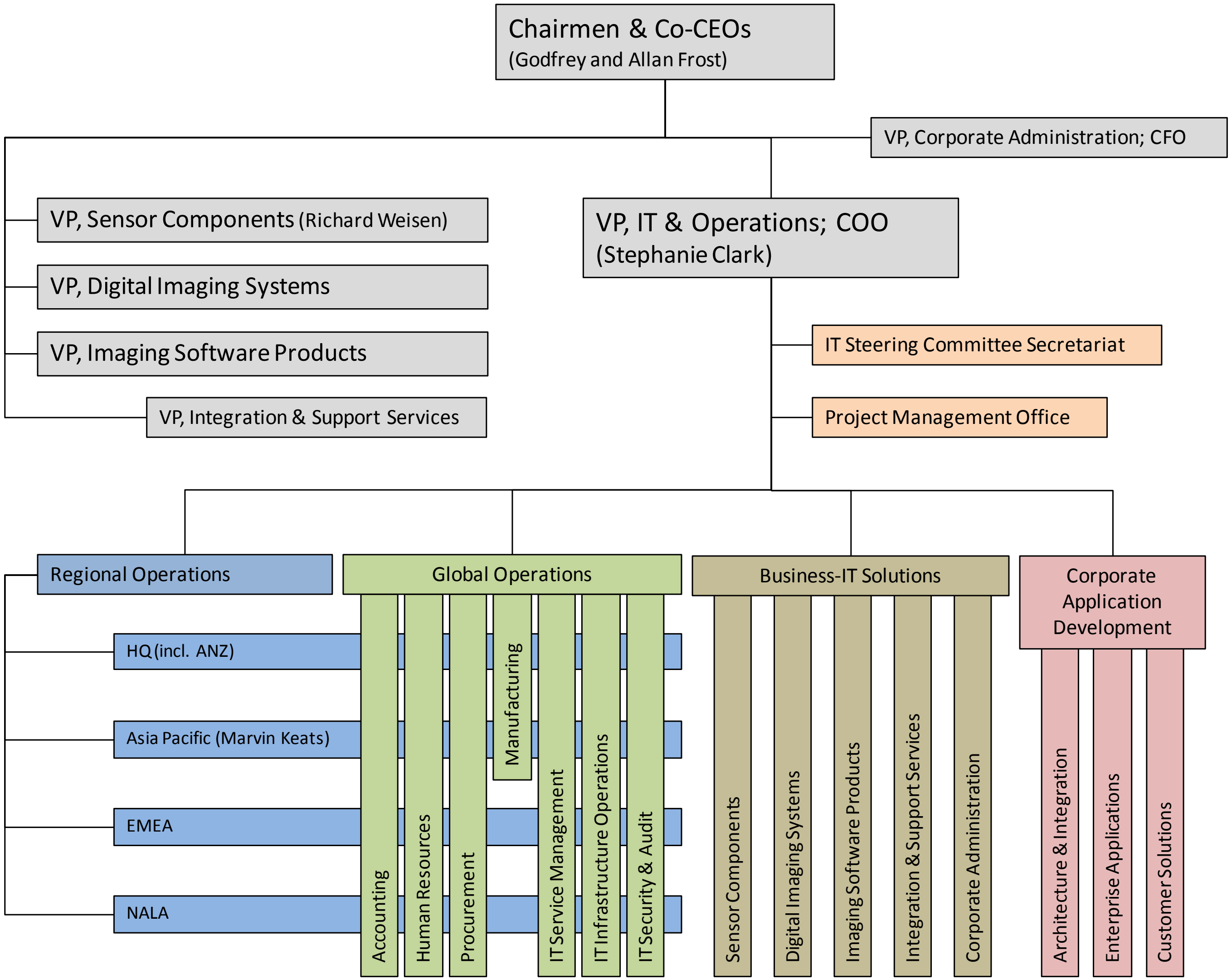


Exhibit 4: Terra Firma's IT Budget in 2009

Region	Global	HQ	A/P	EMEA	NALA
Capital expenses					
Computer hardware	32.6	19.2	5.2	4.6	3.6
Software licenses	18.6	11.7	2.1	2.6	2.2
Network equipment	16.8	7.5	3.9	2.9	2.5
Data center equipment	25.2	16.4	8.8		
Total capital expenses	93.2	54.9	19.9	10.0	8.3
Operating expenses					
Infrastructure operations	19.1	10.5	3.8	2.9	1.9
Applications and development	40.5	30.4	6.1	2.4	1.6
Total operating expenses	59.6	40.9	9.9	5.3	3.5
Grand total (cash flow basis)	152.8	95.8	29.8	15.3	11.9
Depreciation and amortization	31.7				
Grand total (accrual basis)	91.3				

Note: Units in millions of New Zealand dollars.[18]

Key to regions

HQ Headquarters facilities in the Wellington area, plus 4 field offices in Australia and New Zealand, DigiRayZ manufacturing plant in Melbourne, Australia. Employees: about 3,100.

A/P Asia Pacific. 7 field offices and TFT manufacturing plant in Penang, Malaysia. Regional HQ: Singapore. Largest field office: Tochigi, Japan. Employees: about 800.

EMEA Europe, Middle East and Africa. 6 field offices. Regional HQ: Brussels. Largest field office: Erlangen, Germany. Employees: about 700.

NALA North America and Latin America. 5 field offices. Regional HQ: Chicago. Largest field office: Waukesha, Wisconsin. Employees: about 600.

[18] Some material in this exhibit is adapted from chapter 4 of R. D. Austin, R. L. Nolan and S. O'Donnell (2009), *The Adventures of an IT Leader*, Harvard Business School Press.

Exhibit 5: Terra Firma's IT Service Management Process

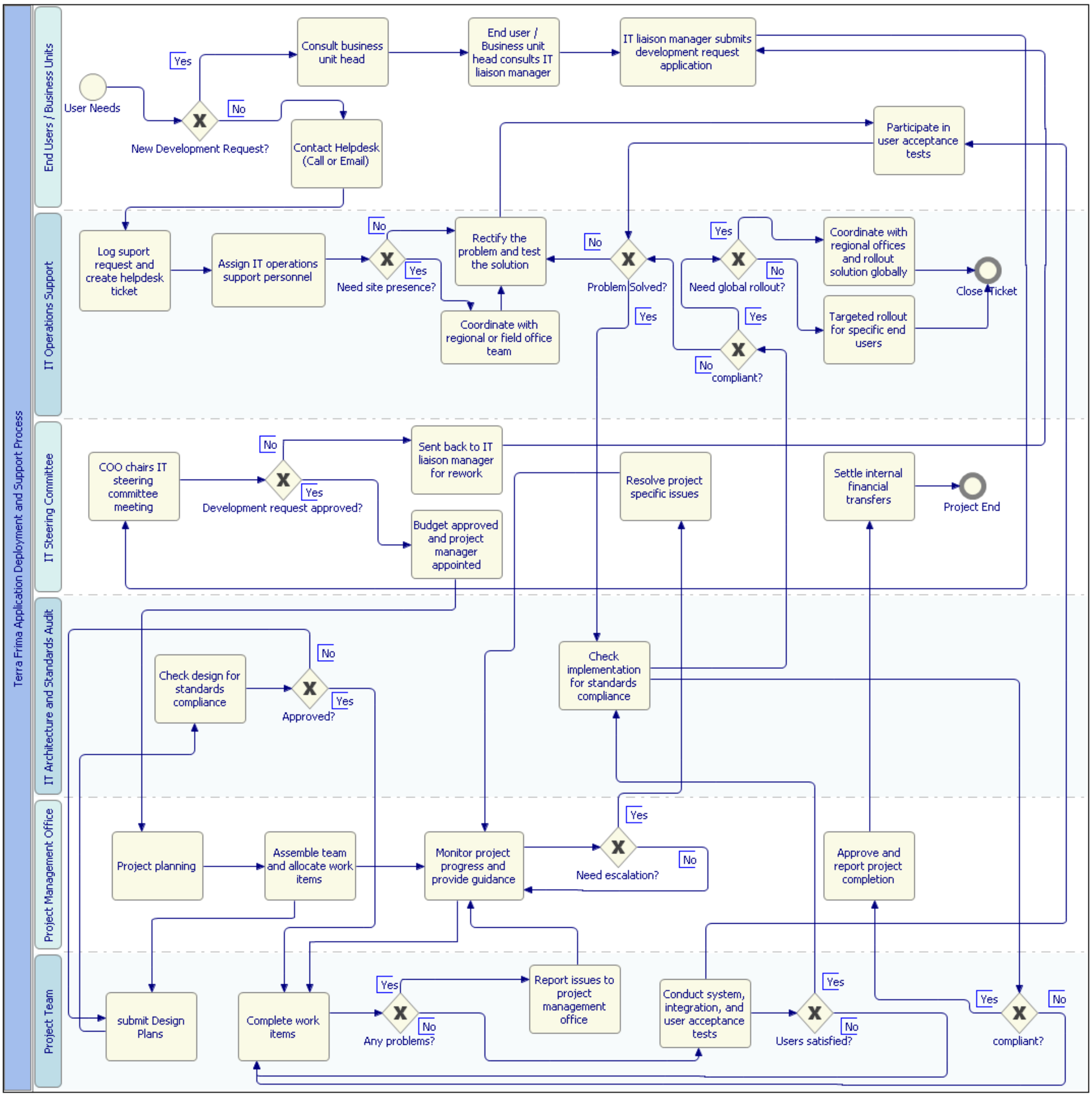


Exhibit 6: Terra Firma's Key IT Applications and Services

Application / Service	Description / Notes	Funding Model *	Deployment Location
Basic End-User IT services			
PC support			
• Corp. HQ help desk	Commercial call center software, tools for deploying / managing standard PC system images. Homegrown issue tracking system (Rx@TFM), asset management system (CYAssets).	HC	Gracefield
• Regional HQ help desk	Full-time IT operations staff of 3–5 people each. No dedicated help desk but someone always available during office hours to take calls, and someone on call 24 hours for critical operational issues (e.g., network goes down).	HC	Regional HQs
• Field office help desk	Field offices usually hire 1–2 local IT support people on a contract basis. Call regional HQ for higher-level support (e.g., Singapore for Asia Pacific).	HC	Field offices
Email / calendar			
• MS Exchange / Outlook	Microsoft Outlook / Exchange 2003. Some people use for calendaring but most don't.	HC	Gracefield
• Mobile devices	Corporate BlackBerries for some field staff and key executives, other people sync to personal devices (iPhone) and services (Google Calendar). Some concerns about data leakage (esp. from engineering teams) but no formal policy yet.	CB + free	Various
Videoconferencing			
• Site	Polycom videoconferencing equipment connecting Penang and key field offices (US, Europe, Japan) to HQ via ISDN.	CB	Various
• Desktop	Newer field offices using free desktop videoconferencing software (e.g., Skype), but no supported corporate solution.	BR for pilot	Various
Collaboration			
• File sharing	Departmental Windows-based file and print servers (Novell servers migrated in 2000).	CB	Various
• Social media	Some experiments with wikis, IM, SharePoint, but no corporate standard.	BR for pilot	Various

Application / Service	Description / Notes	Funding Model *	Deployment Location
Corporate Enterprise Systems			
ERP			
• J.D. Edwards	Still running on IBM AS/400 platform. Recently extended to Penang for plant management, replacing proprietary Intel software.	BR	Gracefield, Penang
• Infor ERP XA	Used at Melbourne plant (acquired with X-ray systems company); also running on AS/400 (a.k.a. IBM System i platform).	BR	Melbourne
SCM			
• Procurement (downstream)	Big customers (GE, Siemens, etc.) require use of their own procurement portals. Developed mix of off-the-shelf connectors and internally developed glue code to connect into JDE.	BR	Gracefield
• Procurement (upstream)	Some Terra Firma suppliers able / willing to interface with J.D. Edwards. Others processed manually by procurement staff. Engineers also need visibility (e.g., to look up part catalogs).	BR	Gracefield
HRM			
• J.D. Edwards	For basic employee record / payroll functionality. Full support in HQ area, partial support in the geographies (little customization done so lots of separate tracking needs to happen at the country level, e.g., tax withholding).	BR	Gracefield
• Benefits, leave tracking, expense reimbursement	Homegrown apps for HQ area. Mostly ad hoc solutions in the geographies (e.g., Excel spreadsheets maintained by office managers).	BR	Gracefield
CRM			
• Oracle CRM (f.k.a. Siebel)	Installed on Windows clients at field offices. Costly and time-consuming to add users, which is happening a lot as new offices grow and more staff join.	BR	Gracefield, Field offices
• Rel. mgmt. for large vendors	Key vendor relationships mostly managed "by hand" and by sharing documents between HQ and field offices. Some custom apps written, few used widely or maintained.	CB	Gracefield, Field offices
BI			
• Corporate reporting	Some reports (e.g., financial statements) produced directly by J.D. Edwards. Most others prepared using Excel, some automated with VBA scripting.	BR	Corp. HQ, Regional HQs
• Data mining / warehousing	SAS and Cognos used for more sophisticated data mining.	CB	Gracefield, Field offices

Application / Service	Description / Notes	Funding Model *	Deployment Location
Product Development / Manufacturing			
Hardware engineering			
• Electronic Design Automation (EDA)	Mix of Synopsys, Cadence and Mentor Graphics running on high-end UNIX workstations (now Intel-based). Low utilization rate, but engineers prefer having on desk rather than sending batch jobs to server.	CB	Kelburn
• Simulation / analysis	48-node Beowulf cluster for numerical computation. Mainly running apps developed by product engineering groups, plus general-purpose scientific software (e.g., MATLAB).	CB	Kelburn
• Issue tracking	Homegrown application for tracking Requests for Engineering (RFEs).	CB	Kelburn
Software engineering			
• Application development	Standard commercial and open-source software development (e.g., MS Visual Studio, Eclipse). Mix of Windows, Mac, Linux operating system platform.	CB + free	Miramar
• Graphics rendering	Mix of homegrown and commercial rendering software. Not deployed at scale (desktop only).	CB	Miramar
• Testing lab	15 machines running different versions of Windows and Mac OS X. Some automated testing software.	CB	Miramar
Manufacturing			
• QA / Test	Locally developed apps in Penang for quality assurance and testing. Generates lots of data, some of which needs to be accessed by HW engineering staff at Kelburn.	CB	Penang, Melbourne, Gracefield
• Production control	Software in Penang largely inherited from Intel. Major issue is retaining skills needed to maintain and upgrade.	CB	Various
IPR / compliance			
• EMC Documentum	For regulatory compliance (FDA, etc.) as well as patent filing.	CB	Kelburn

** Funding models: HC = headcount tax, BR = budget request, CB = internal chargeback.*

Exhibit 7: Terra Firma's Corporate IT Architecture (Network View)

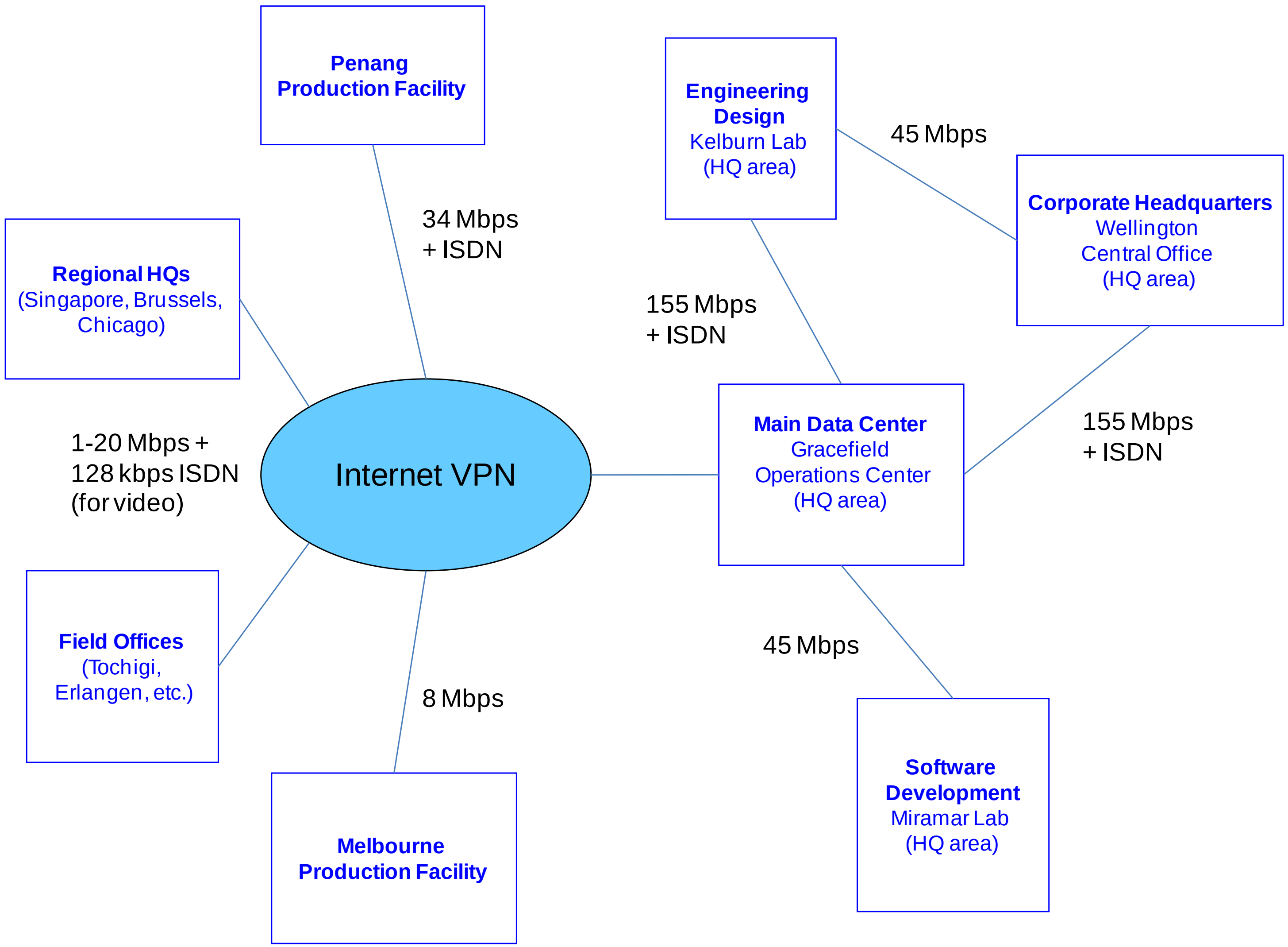
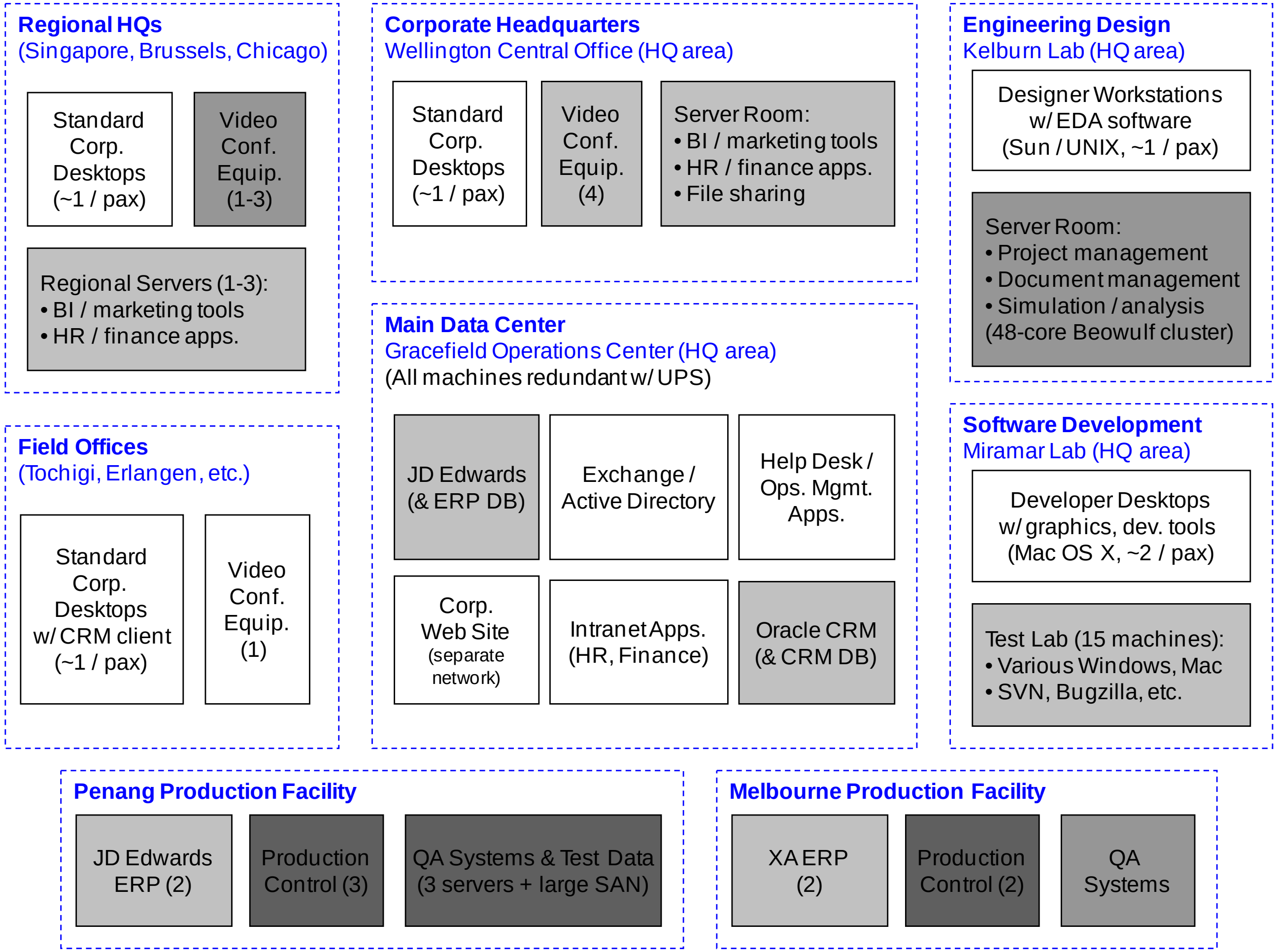


Exhibit 8: Terra Firma's Corporate IT Architecture (Deployment View)



Note: Darker shading indicates higher load.

Exhibit 9: Terra Firma's Corporate IT Architecture (Collaboration View)

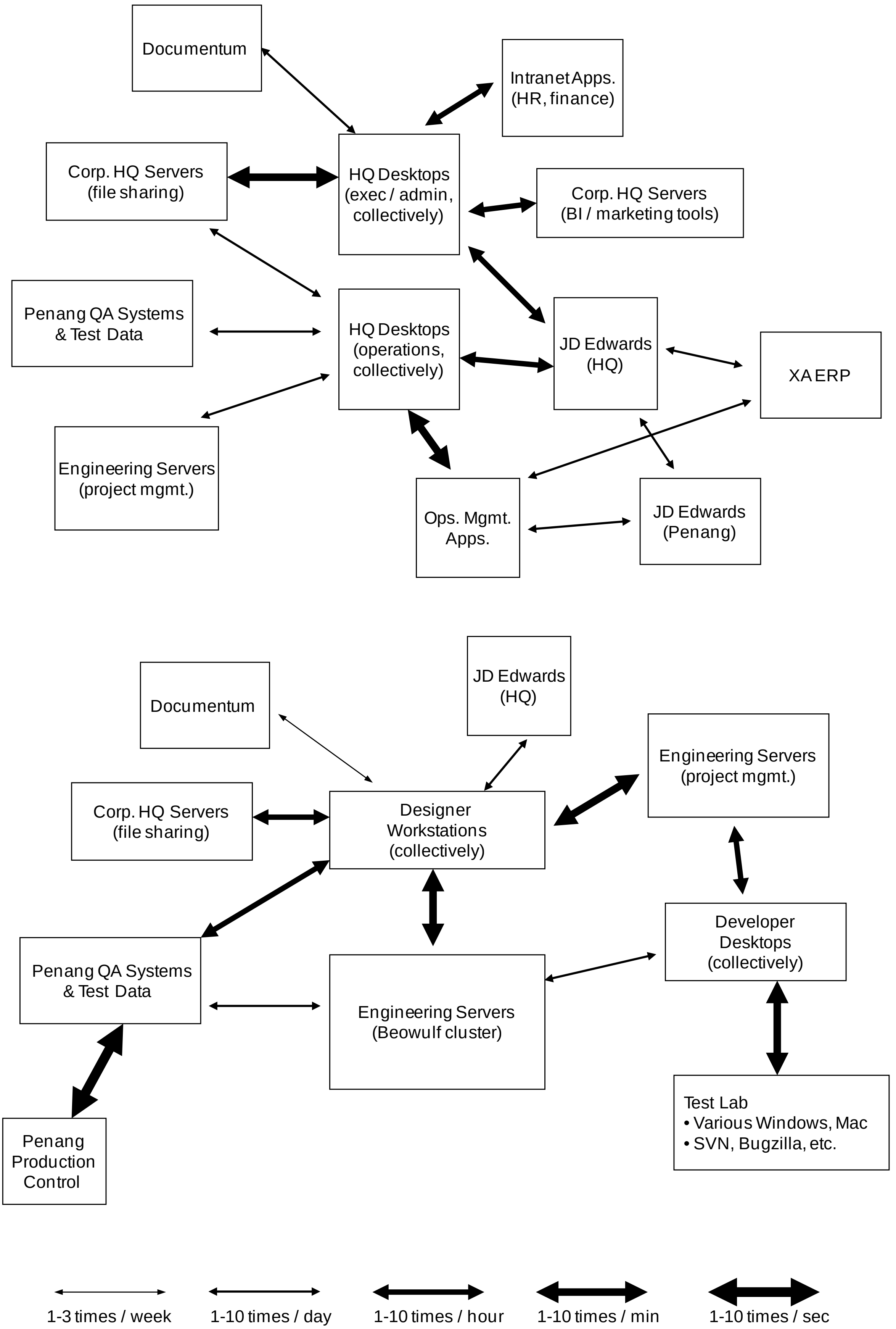


Exhibit 10: Terra Firma's Corporate IT Architecture (Data Flow View)