A Tale of Two Projects: The Panama Canal and the Birth of Project and Risk Management

Tom Kendrick, PMP, Program Manager
San Carlos, CA
TKendrick@FailureProofProjects.com

Abstract

The construction of the Panama Canal nearly 100 years ago was the most risky, high-tech project of its day. Much of the engineering required was developed for the project. The construction was breathtakingly expensive—until the late twentieth century the Panama Canal represented the single largest project investment in modern times. Stretching over several decades and requiring a series of project leaders, the construction effort and other contemporary projects represented the birth of modern project management.

The Panama Canal story is particularly interesting for project managers because it is actually the story of two attempts at the same project. The first effort to build the Canal, by Ferdinand de Lesseps in the 1880s, was a project failure of epic proportions. The disastrous outcome was due to a number of factors, but lack of good project and risk management were front and center. The second project in the early 1900s, planned and led by John Stevens and George Goethals, succeeded largely because of the rigorous and disciplined application of good project practices, especially risk management.

Material for this presentation is based in part on content from Identifying and Managing Project Risk (Tom Kendrick, AMACOM, 2003), where the Panama Canal projects are used to show the value and durability of project risk management principles. The ideas that ultimately made the Canal possible—what worked and what didn't work—are ideas that are very much alive and valid today.

The first Panama Canal project

Although there was speculation much earlier, the first serious consideration of a canal in Central America was in the mid-1800s. Estimates were that such a canal would provide $48 million a year in shipping savings, and might be built for less than $100 million. Further study of a canal on-site was less optimistic, but construction of a railroad across the Isthmus of Panama was begun in 1850. This railroad was ultimately completed, but the $1.5 million, two-year project swelled to $8 million before it was finished, three years late in 1855. Eventually the railroad was able to generate a profit, but its construction problems held lessons for the canal construction efforts to come.

Shortly after successfully completing the Suez Canal in 1869, Ferdinand de Lesseps and his backers were eager to take on new challenges. This financial and technical triumph earned de Lesseps the nickname "The Great Engineer," although he was actually a diplomat by training, and had no technical background at all (and only modest skills as an administrator). He had, however, completed a project many thought to be impossible, and was now world famous. Examining the world map, de Lesseps decided a canal at Panama would be his next project. Working from Paris in the late 1870s, he negotiated the necessary agreements in Bogota, Colombia (Panama was then the northernmost part of Colombia), securing the rights to build and operate a canal there in exchange for a small percentage of the revenue to be generated over 99 years.

While it might seem curious today that these Middle Eastern and Central American projects originated in France, in the late 1800s Paris was the center of the engineering universe. The best schools in the world were there, and many engineering giants of the day lived in Paris, including Gustav Eiffel (then planning his tower). Engineering projects such as these could hardly have arisen anywhere else.

Prior successes and good intentions notwithstanding, the initial undertaking to construct a canal at Panama was, in retrospect, very premature. It was a massive challenge for the technology of the late 1800s. In addition, a lack of project management expertise, just emerging at that time, compounded their difficulties. Precise project definition was never clear, even years into the project. Planning was never thorough, and changes in the work were frequent and managed only informally. Reporting on the project was sporadic and generally inaccurate (or even dishonest). Risks were not effectively identified or were ignored, and the primary risk management strategy appears to have been “hoping for the best.”

Initial definition for the Panama Canal project started in 1879 at the “International Congress” to study the feasibility of a canal connecting the Atlantic and Pacific oceans through Central America sponsored by Ferdinand de Lesseps. Over a hundred delegates gathered in Paris, mostly from France, and they considered number of routes for the canal, were, recommending possibilities through both Nicaragua and Panama. Construction ideas, including a very realistic “lock-and-dam” concept (somewhat similar to the canal in service today) were also considered. In the end, though, the Congress voted to support a sea-level canal project at Panama, even though nearly all the engineers present thought the idea infeasible and voted against it. Not listening to technical people is a perilous way to start a project. The Panama Canal was neither the first nor the last project to create its own problems due to ignoring technical input.

Planning for the project was never a high priority. De Lesseps had little interest in technical problems; he believed innovations would appear in response to needs as they had at Suez, and the future would take care of itself. He valued only his own opinions and ignored the views of those who disagreed with him, even recognized authorities. An inveterate optimist, he was convinced, based only on self-confidence, that he could not fail. These attitudes are not conducive to good risk management; there are few things more dangerous to a project than an overly optimistic project leader.

The broad objective de Lesseps set for his Compagnie Universal du Canal Interoceanique was to build a sea-level canal in 12 years, to open in 1892. He raised the equivalent of $60 million from investors through public offerings—a lot of money, but still less than one third of the initial engineering cost estimate of more than $200 million. In addition to this financial shortfall, essentially the only detailed planning done before work actually commenced was done at the 1879 meeting in Paris by people who had never seen Panama. Even on the visits that de Lesseps did make to Panama, he took along no technical people.

Eventually the engineers did get to Panama, and digging finally started in 1882. soon the estimates of the volume of excavation required started to rise, to almost triple the estimates used in 1879. As the magnitude of the effort rose, de Lesseps made no public changes to his cost estimates or to the completion date.

Risks management on the project was ignored at the start, and it improved little in the early stages of execution. There were many problems. Panama is in the tropics, and torrential rains for much of the year created floods that impeded the digging and made the work very dangerous. The frequent rains turned Panama's clay into a flowing, sticky sludge that bogged down work, and the moist, tropical salt air combined with the viscous mud to destroy the machinery. There was also the issue of elevation. The continental divide in Panama is insignificant compared with the mountains in North or South America, but it does rise to more than 130 meters. For a canal to cross the Panama at sea level, it would be necessary to dig a trench more than 15 kilometers long to this depth, an unprecedented excavation. Digging the remainder of the 80-kilometer transit across the isthmus was not much less daunting. Adequate funding for the work was also a problem, as only a portion of the money that was raised was allocated to construction (most of the money went for publicity, including a very impressive periodic Canal Bulletin, used to build interest and support). Worst of all, diseases, especially malaria and yellow fever, were lethal to many workers not native to the tropics, who died by the hundreds. As work progressed, the engineers, already dubious, increasingly believed the plan to dig a sea-level canal was doomed.

Intense interest in the project and a steady stream of new workers kept work going, and the Canal Bulletin reported good progress (regardless of what was actually happening). As the project progressed there were changes. Several years into the project, in 1885, the cost estimates were finally raised, and investors provided new funds that quadrupled the project budget to US$240 million. The expected opening of the canal was delayed "somewhat," but no specific date was offered. Claims were made at this time that the canal was half dug, but the truth was probably less than 15 percent. Information on the project was far from trustworthy.

In 1887 costs were again revised upward, exceeding $330 million. The additional money was borrowed, as de Lesseps could find no new investors. Following years of struggle and frustration, the engineers finally won the debate over construction of a canal at sea level. Plans were shifted to construct dams on the rivers near each coast to create large lakes that would serve as much of the transit. Sets of locks would be needed to bring ships up to, and down from, these man-made lakes. While this would slow the transit of ships somewhat, it significantly reduced the necessary excavation.

Even with these changes, problems continued to mount, and by 1889 more revisions and even more money were needed. After repeated failures to raise funding, de Lesseps liquidated the Compagnie Universal du Canal Interoceanique, and the project ended. This collapse caused complete financial losses for all the investors. By 1892 scandals were rampant, and the bad press and blame spread far and wide. Soon the lawyers and courts of France were very busy dealing with the project's aftermath.

The French do not seem to have done a formal postproject analysis, but looking at the project in retrospect reveals over a decade of work, more than $300 million spent, lots of digging, and no canal. Following the years of effort, the site was ugly and an ecological mess. The cost of this project also included at least 20,000 lives lost (many workers who came to Panama died so soon after their arrival that their deaths were never recorded; some estimates of the death toll run as high as 25,000). Directly as a result of this project failure, the French government fell in 1892, ending one of the messiest and most costly project failures in history.

The leader of this project did not fare well in the wake of this disaster. Ferdinand de Lesseps was not technical, and he was misguided in his beliefs that equipment and medicines would appear when needed. He also chronically reported more progress than was real (through either poor analysis or deception; the records are not clear enough to tell). He died a broken man, in poverty. Had he never undertaken the project at Panama, he would have been remembered as the heroic builder of the Suez Canal. Instead, his name is also linked forever to the failure at Panama.

Perhaps the one positive outcome from all this was clear evidence that building a sea-level canal at Panama was all but impossible due to the rains, flooding, geology, and other challenges. These are problems that probably could not be surmounted even with current technology.

While it is not possible ever to know whether a canal at Panama could have been constructed in the 1880s, better project and risk management practices, available at the time, would have helped substantially. Setting a more appropriate initial objective, or at least modifying it sooner, would have improved the likelihood of success. Honest, more frequent communication—the foundation of well-run projects—would almost certainly have either forced these changes or led to earlier abandonment of the work, saving thousands of lives and a great deal of money.

A second Panama Canal project—once more with feeling

"A man, a plan, a canal. Panama"

Successful projects are often not the first attempt to do something. Often, there is a recognized opportunity that triggers a project. If the first attempted project fails, it discourages people for a time. Soon, however, if the opportunity remains attractive another project will begin, building on the work and the experiences of the first project. A canal at Panama remained an attractive opportunity. When Theodore Roosevelt became president in 1901, he decided to make successful completion of a Central American canal part of his presidential legacy. (And so it is. He is the “man” in the famous palindrome.)

As much as the earlier French project failed due to lapses in project management, the U.S. project ultimately succeeded as a direct result of applying good project and risk management principles.

Unlike the initial attempt to build a canal, the U.S. effort was not a commercial venture. Maintaining separate U.S. navies on the East and West coasts was becoming increasingly costly. Consolidation into a single larger navy required easy transit between the Atlantic and Pacific, so Theodore Roosevelt saw the Panama Canal as a strategic military project, not a commercial one.

The U.S. venture started again with a debate over routes—Nicaragua vs. Panama—and based on technical analysis, they selected Panama. Unlike Ferdinand de Lesseps, Theodore Roosevelt was a more typical project sponsor. He delegated the management of the project to others. His greatest direct contribution to the project was in “engineering” the independence of Panama from Colombia. (This “revolution” was accomplished by a pair of gunboats, one at Colon in the Gulf of Mexico and another at Panama City on the Pacific. Without the firing of a single shot, the independent nation of Panama was created in 1902. Repercussions of this U.S. foreign policy decision persist, more than a century later.) To get the project started quickly, Roosevelt also moved to acquire the assets of what remained of de Lessep’s company.

“I took the isthmus!” Roosevelt said. He then went to the U.S. Congress to get approval to go forward with the building of the canal. Following all this activity and the public support it generated, Congress had little choice but to support the project. While the specifics for the project were still vague, the intention of the United States was clear: to build a canal at Panama capable of transporting even the largest U.S. warships, and to build it as quickly as was practical.

Insight into Roosevelt’s thinking concerning the project is found in this quote from 1899, two years before his presidency:
Far better it is to dare mighty things, to win glorious triumphs, even though checkered by failure, than to take rank with those poor spirits who neither enjoy much nor suffer much, because they live in the gray twilight that knows not victory nor defeat.

Project sponsors often aspire to “dare mighty things.” They are much more risk tolerant than most project leaders and teams. Good risk management planning serves to balance the process of setting project objectives, so we undertake projects that are not only worthwhile and challenging but also possible.

Setting the Objective

One of the principal differences between the earlier unsuccessful attempt to build the Panama Canal and the later project was the application of good project management practices. While this was ultimately true, the new project had a shaky beginning. Conceived as a military project and funded by the U.S. government, the scope and objectives for the revived Panama Canal project should have been very clear, even at the start. They were not.

The initial manager for the project when work commenced in 1904 was John Findlay Wallace, formerly the general manager of the Illinois Central Railroad. Wallace was visionary; he did a lot of investigating and experimenting but he accomplished very little in Panama. His background included no similar project experience. In addition to his other difficulties, he could do almost nothing without the consent of a seven-man commission set up back in the United States, a commission that rarely agreed on anything. Also, nearly every decision, regardless of size, required massive amounts of paperwork. A year later, in 1905, US$128 million had been spent but still there was no final plan, and most of the workers were still waiting for something to do. The project had in most ways picked up just where the earlier French project had left off, problems and all. Even after a year, it was still not clear whether the canal would be at sea level or constructed with locks and dams. In 1905, mired in red tape, Wallace announced the canal was a mistake, and he resigned.

John Wallace was promptly replaced by John Stevens. Stevens was also from the railroad business, but his experience was on the building side, not the operating side. He built a reputation as one of the best engineers in the United States by constructing railroads throughout the Pacific frontier. Prior to appointing Stevens, Theodore Roosevelt eliminated the problematic seven-man commission, and he significantly reduced the red tape, complication, and delay. As Chief Engineer, Stevens, unlike Wallace, effectively had full control of the work. Arriving in Panama, Stevens took stock and immediately stopped all work on the canal, stating, "I was determined to prepare well before construction, regardless of clamor of criticism. I am confident that if this policy is adhered to, the future will show its wisdom." And so it did.

With the arrival of John Stevens, managing project scope became the highest priority. He directed all his initial efforts at preparation for the work. He built dormitories for workers to live in, dining halls to feed them, warehouses for equipment and materials, and other infrastructure for the project. The doctor responsible for health of the workers on the project, William Crawford Gorgas, had been trying for over a year to gain support from John Wallace for measures needed to deal with the mosquitoes, by then known to spread both yellow fever and malaria. Stevens quickly gave this work his full support, and Dr. Gorgas proceeded to eradicate these diseases. Yellow fever was conquered in Panama just six months after Dr. Gorgas received Stevens's support, and he made good progress combating malaria as well.

Under the guidance of Stevens, all the work was defined and planned employing well-established, modern project management principles. He said, "Intelligent management must be based on exact knowledge of facts. Guess work will not do." He did not talk much, but he asked lots of questions. People commented, "He turned me inside out and shook out the last drop of information." His meticulous documentation served as the basis for work throughout the project.

Stevens also determined exactly how the canal should be built, to the smallest detail. The objective for the project was ultimately set in 1907 according to his recommendations: The United States would build an 80-kilometer (50-mile), lock-and-dam canal at Panama connecting the Atlantic and Pacific oceans, with a budget of US$375 million, to open in 1915. With the scope defined, the path forward became clear.

Planning

Early in his work in Panama, John Stevens spent virtually all of his time among the workers, asking questions. His single-minded pursuit was planning the project well and thoroughly. Stevens put all he learned into the plans, setting the foundation required to get the project moving forward.

The primary tool for construction was one Stevens was very familiar with: the railroad. He recognized that digging enormous trenches was only part of the job. Excavated soil had to be moved out of the cut in central Panama where someday ships would pass, and it had to be deposited near the coasts to construct the required massive earthen dams. In the rain forests of Panama at the turn of the twentieth century, the railroad was not only the best way to do this, it was the only practical way. Much of the planning that Sevens did centered on using the railroad, and by early in 1906, he had documented exactly how this was to be done. When excavation resumed, his elaborate, "ingeniously elastic" use of the railroad enabled progress at a vigorous pace, and it continued virtually nonstop through completion of the work.

Once Stevens had broken the work down into smaller, easily understood activities, the canal project began to look possible. Each part of the job was now understood to be something that had been done, somewhere, before. It became a matter of getting it all done, one activity at a time.

For all his talents and capabilities, John Stevens never considered himself fully qualified to manage the entire project. His experience was with surveying and building railroads. The canal project involved building massive concrete locks (like enormous bath tubs with doors on each end) that would raise ships nearly 30 meters from sea level and lower them back again—12 structures in all. The project also required a great deal of knowledge of hydraulics; moving enormous amounts of water quickly was essential to efficient canal operation. Stevens had no experience with either of these types of engineering. These gaps in his background, coupled with his dislike of the hot, humid climate and the omnipresent (and still dangerous) insects, led him to resign as Chief Engineer after two years, in 1907.

This did not sit well with Theodore Roosevelt. Losing such a competent project leader was a huge risk to the schedule. Both of his project leaders had resigned before completing his most important project, and Roosevelt was determined that this would not happen again. To replace John Stevens, Roosevelt selected George Washington Goethals, an immensely qualified engineer. Goethals had been seriously considered for the job twice previously and was ideally qualified to build the Panama Canal. He had completed a number of similar, smaller projects, and he had a great deal of experience with nearly all the work required at Panama.

Theodore Roosevelt wanted more than competence, however. For this project, he wanted "men who will stay on the job until I get tired of having them there, or until I say they may abandon it." His new Chief Engineer and project leader could not resign; George Goethals was a major (soon to be lieutenant colonel) in the U.S. Army Corps of Engineers. If Goethals tried to resign, he could be court-martialed and sent to jail.

Resources

Project resource risk arises primarily from people factors, as demonstrated in the PERIL database, and this was certainly true on the Panama Canal project. Based on the experiences of the French during the first attempt, John Stevens realized project success required a healthy, productive, motivated workforce. For his project money was never an issue, but retaining people to do difficult and dangerous work in the hot, humid tropics certainly was. Stevens invested heavily, through Dr. Gorgas, in insect control and other public health measures. He also built an infrastructure at Panama that supported the productive, efficient progress he required. At the time of his departure from the project, Stevens had established a well-fed, well-equipped, well-housed, well-organized work force with an excellent plan of attack.

This boosted productivity, but George Goethals realized that success also relied on continuity and motivation. He wanted loyalty, not to him, but to the project. The work was important, and Goethals used any opportunity he had to point this out. He worked hard to keep the workers engaged, and much of what he did remains good resource management practice today.

Goethals took a number of important steps to build morale. He started a weekly newspaper, the Canal Record. The paper gave an accurate, up-to-date picture of progress, unlike the Canal Bulletin periodically issued during the French project. In many ways, it served as the project's status report, making note of significant accomplishments and naming those involved to build morale. The paper also provided feedback on productivity. Publishing these statistics led to healthy rivalries, as workers strived to better last week's record for various types of work, so they could see their names in print.

It was crucial, Goethals believed, to recognize and reward service. Medals were struck at the Philadelphia Mint, using metal salvaged from the abandoned French equipment. Everyone who worked on the project for at least two years was publicly recognized and presented with a medal in a formal ceremony. People wore these proudly. In a documentary made many years after the project, Robert Dill, a former canal worker interviewed at age 104, was still wearing his medal, number 6726.

Goethals also sponsored weekly open-door sessions on Sundays when anyone could come with their questions. Some weeks over one hundred people would come to see him. If he could quickly answer a question or solve a problem, he did it then. If a request or suggestion was not something that would work, he explained why. If there were any open questions or issues, he committed to getting an answer, and he followed up. Goethals treated workers like humans, not brutes, and this engendered fierce loyalty.

While all this contributed to ensuring a loyal, motivated, productive workforce, the most significant morale builder came early on, from the project sponsor. In 1906, Theodore Roosevelt sailed to Panama to visit his project. Roosevelt's trip was without precedent; never before had a sitting U.S. president left the country. The results of the trip were so noteworthy that one newspaper at the time conjectured that someday, a president "might undertake European journeys."

Roosevelt chose to travel in the rainy season, and the conditions in Panama were dreadful. This hardly slowed him down at all; he was in the swamps, walking the railroad ties, charging up the slopes, even operating one of the huge, 97-ton Bucyrus steam shovels. He went everywhere the workers were. The reporters who came along were exhausted, but the workers were hugely excited and motivated.

On Roosevelt's return to Washington, so much was written about the magnitude and importance of the project that interest and support for the canal spread quickly throughout the United States. People believed, "With Teddy Roosevelt, anything is possible."

Improving the Plan

Many impossible projects, viewed in retrospect, failed because they could not manage the work within mandated constraints. In reviving the Panama Canal project, a great deal of effort went into rethinking the approach to the work, to avoid the most significant issues that plagued the earlier project.

For projects of all types, it is beneficial to invest effort early investigating whether there are better, faster, more efficient ways to do what is required. New technologies, methodologies, and approaches are born this way. Several key innovations were introduced in the U.S. canal project. Avoiding schedule and cost problems required changes to the equipment used and the methods employed to accomplish the work.

On the equipment side, twentieth-century technology made possible the huge, powerful steam shovels that gave the U.S. effort a big advantage over the earlier project. New technology also provided equipment suitable for use in the warm, damp, machine-destroying environment of Panama.

As important as the hardware was, however, the way the equipment was used made an even bigger difference. John Stevens, as a railroad engineer, saw the canal project as a railroad problem. To him, the canal was "the greatest of all triumphs in American railroad engineering." To keep the huge shovels digging continuously, Stevens developed a system so that shovel loads could be dropped onto railroad flatcars that ran along track adjacent to the shovels. The flatcars circulated in large loops out to the dams and other places where these loads could be deposited. Once there, huge fixed scoops (similar to the fronts of enormous snowplows) cleaned off the flatcars for their return to the shovels, with no need to stop or pause at any point for this enormous conveyor belt. Using this arrangement and the much larger steam shovels, the U.S. project was soon excavating more in one day than the earlier French project had accomplished in a month.

This system would have been sufficient for the project if the shovels had been simply digging deep holes in one place, but they were not. As the digging proceeded, the shovels had to move, and so did the railroad tracks that carried the flatcars. For this, John Stevens developed an elaborate, elastic method for moving the track, providing a constant, steady stream of empty flatcars flowing by the steam shovels. With this system, twelve men could move almost two kilometers of track in a single day. Using conventional track-laying methods, 600 men would have had difficulty equaling this performance. As the construction continued, excavation in the Culebra Cut widened and deepened, so these methods were used at multiple levels. Each level had its own railroad loop, shovels, and crews. The total track moved in one year approached 2000 kilometers (over 1,000 miles). Without these innovations, the canal project would have taken years longer to complete and cost far more, and it might well have been abandoned before completion, like the earlier project.

Risks

As with any project of the canal's size and duration, risks were everywhere. Based on assessment of cost and probability, the most severe were diseases, mud slides, the constant use of explosives, and the technical challenges of constructing the locks.

Diseases were less of a problem on the U.S. project, but health remained a concern. Both of the first two managers cited tropical disease among their reasons for resigning from the project. Life in the tropics in the early 1900s was neither comfortable nor safe. The enormous death toll from the earlier project made this exposure a top priority.

Mudslides were common for both the French and the U.S. projects, as the soil of Panama is not stable, and earthquakes made things worse. Whenever the sloping sides of the cut collapsed, there was danger to the working crews and potential serious damage to the digging and railroad equipment. In addition to this, it was demoralizing to face the repair and rework following the each slide, and the predicted additional effort required to excavate repeatedly in the same location multiplied the cost of construction. This risk had very high impact to both schedule and budget; despite precautions, major setbacks were frequent.

Explosives were in use everywhere. In the Culebra Cut, massive boulders were common, and workers set off dynamite charges to reduce them to moveable pieces. The planned transit for ships through the man-made lakes was a rain forest filled with large, old trees, and these, too, had to be removed with explosives. In the tropics especially, the dynamite of that era was not very stable. It exploded in storage, in transit to the work sites, while being set in place for use, and in many other unintended situations. The probability of premature detonation was high, and the risk to human life was extreme.

Beyond these daunting risks, the largest technical challenge on the project was the locks. They were gigantic mechanisms, among the largest and most complex construction ever attempted. Although locks had been used on canals for a very long time, virtually all of them had been built for smaller boats navigating freshwater rivers and lakes. Locks had never before been constructed for large ocean-going ships. (The canal at Suez has no locks; as with the original plan for Panama, it is entirely at sea level.) The doors for the locks were to be huge, and therefore very heavy. The volume of water held by the locks when filled was so great that the pressure on the doors would be immense, and the precision required for the seams where the doors closed to hold in the water was also unprecedented for man-made objects so large. The locks would be enormous boxes with sides and bottoms formed of concrete, which also was a challenge, particularly in an earthquake zone. For all this, the biggest technological hurdle was the requirement that all operations be electric. Because earlier canals were much smaller, usually the lock doors were cranked open and shut and the boats were pulled in and out by animals. (To this day, the trains used to guide ships into and out of the locks at Panama are called "electric mules.") The design, implementation, and control of a canal using the new technology of electric power—and the hydroelectric installations required to supply enough electricity—all involved emerging, poorly understood technology. Without the locks, the canal would be useless, and the risks associated with resolving all of these technical problems were large.

These severe risks were but a few of the many challenges faced on the canal project, but each was singled out for substantial continuing attention. In the next chapter, in which tactics for dealing with risk are covered, what was done to manage these challenges in Panama is discussed.

Risk Plans

Risk management represented one of the largest investments for the Panama Canal project. Of the risks mentioned in Chapter 7, most were dealt with in effective, and in several cases innovative, ways.

The risk of disease, so devastating on the earlier project, was managed through diligence, science, and sanitation. The scale and cost of this effort was significant, but so were the results. Widespread use of methods for mosquito control under the guidance of Dr. William Gorgas was effective on a scale never seen before. Specific tactics used, such as frequently applying thin films of oil on bodies of water and the disciplined dumping of standing water wherever it gathered (which in a rain forest was nearly everywhere), were so effective that their use worldwide in the tropics continues to this day. Once the program for insect control was in full effect, Panama was by far the healthiest place anywhere in the tropics. Yellow fever was eliminated. Malaria was rare, as were tuberculosis, dysentery, pneumonia, and a wide range of other diseases common at the time. Not only were the diseases spread by mosquitoes virtually eliminated, work also went much faster without the annoyance of the omnipresent insects. Although some estimates put the cost at US$10 for every mosquito killed, the success of the canal project depended heavily on Dr. Gorgas to ensure that the workers stayed healthy. This risk was managed thoroughly and well.

For the risk of frequent and sudden mudslides, there were no elegant solutions. As the work commenced, it seemed to many that “the more we dug, the more remained to be dug.” Unfortunately, this was true; it proved impossible to use the original French plan for the trench in the Culebra Cut to have sides at 45 degrees (a 1:1 slope). This angle created several problems, the largest of which was the frequent mudslides. In addition, the sides of the cut pressed down on the semisolid clay the excavators were attempting to remove, which squeezed it up in the center of the trench. The deeper the digging, the more the sides would sink and the center would rise; like a fluid, it would seek its level. The contingency plan was inelegant but ultimately effective—more digging. The completed canal had an average 4:1 slope, which minimized the mudslides and partially stabilized the flowing clay. This brute-force contingency plan not only resulted in much more soil to dispose of, it represented about triple the work. Erosion, flowing clay, and occasional mudslides continue to this day, and the canal requires frequent dredging to remain operational.

Dealing with the risks involved with building the enormous locks required a number of tactics. As with the mudslides, the massive concrete sides for the locks were handled by brute force and overengineering. Cement was poured at Panama on a scale never done before. The sides of the locks are so thick and so heavily reinforced that even after nearly eighty years of continuous operation, with thousands of ship passages and countless earthquakes, there are very few cracks or defects. The locks still look much as they did when they were new.

The mechanical and electrical challenges were quite another matter. The locks were colossal machines with thousands of moving parts, many huge. Years of advance planning and experimentation led to ultimate success. The canal was a triumph of precision engineering and use of new steels. Vanadium alloy steels used were developed initially for automotive use, and they proved light and strong enough to serve in the construction of doors for the locks. Holding the doors tightly closed against the weight of the water in a filled lock required a lot of mass, mass that the engineers wanted to avoid moving each time the doors were opened or closed. To achieve this, the doors are hollow. Whenever they are closed, they are filled with water before the lock is filled, providing the necessary mass. The doors are then drained before they are opened to allow the ships raised (or lowered) to pass through.

Even with this strategy, moving doors of this size and weight required the power of modern engines. The choice of electrical operation proved very difficult and required much innovation (the first all-electric factory in the United States was barely a year old at the time of this decision), but electricity did provide a number of advantages. With electric controls, the entire canal system can be controlled centrally. Scale models were built to show the positions of each lock in detail. The lock systems are all controlled using valves and switches on the model, and mechanical interlocks beneath the model prevent errors in operation, such as opening the doors on the wrong end of a lock, or opening them before the filling or draining of water is complete. Complete status can be monitored for all twelve locks.

When George Goethals began to set all of this up, he realized that neither he nor anyone else had ever done anything like it. For most of the controls and the 1000+ electric motors the canal required, Goethals managed risk by bringing in outside help. He awarded a sizable contract to a rapidly growing U. S. company known for its expertise in electrical systems. Although they were still fairly small and not known internationally, the General Electric Company had started to attract worldwide attention by the time the Panama Canal opened. This was a huge contract for GE, and it was their first large government contract. Such a large-scale collaboration of private and public organizations was unknown prior to this project. The relationship used by Goethals and GE served as the model for the Manhattan Project during World War II and for countless other modern projects in the United States and elsewhere. For good or ill, the modern military-industrial complex began in Panama.

Despite the project's success in dealing with most risks, explosives remained a significant problem throughout construction. As in many contemporary projects, loss of life and limbs while handling explosives was common. Although stringent safety precautions helped, the single largest cause of death on the second Panama Canal project was TNT, not disease. For this risk, the builders found no solutions or viable alternatives, so throughout the project they were quite literally "playing with dynamite."

Overall Risks

When John Stevens first arrived in Panama, he found a lack of progress and an even greater lack of enthusiasm. He commented, "There are three diseases in Panama. They are yellow fever, malaria, and cold feet; and the greatest of these is cold feet." For the first two, he set Dr. William Gorgas to work, and these risks were soon all but eliminated from the project.

For the "cold feet," Stevens himself provided the cure. His intense planning effort and thorough analysis converted the seemingly impossible into small, realistic steps that showed that the work was feasible; the ways and means for getting the work done were documented and credible. Even though there were still many specific problems and risks on the project, Stevens had demonstrated that the overall project was truly possible. This was quite a turnaround from the John Wallace's belief that the canal venture was a huge mistake.

With Stevens's plan, nearly every part of the job relied on techniques that were in use elsewhere, and almost all the work required had been done somewhere before. Project funding was guaranteed by the U.S. government. There were thousands of people able, and very willing, to work on the project, so labor was never an issue. The rights and other legal needs were not a problem, especially after Theodore Roosevelt had manipulated the politics in both the United States and in Panama to secure them. What continued to make the canal project exceptional was its enormous scale. As Stevens said, "There is no element of mystery involved, the problem is one of magnitude and not miracles."

Planning and a credible understanding of overall project risk is what converts the need for magic and miracles (which no one can confidently promise to deliver) into the merely difficult. Projects that are seen as difficult but possible are the ones that succeed; a belief that a project can be completed is an important factor in how hard and how well people work. When it looks as though miracles will be necessary, people tend to give up, and their skepticism may very well make the project impossible.

Adjusting the Objective

Setting a concrete objective for a project is not necessarily a quick, easy process. In the case of the Panama Canal, although Theodore Roosevelt made the decision to build the canal and the Senate approved the commitment in early 1904, the specifics of exactly what sort of canal would be built were still not settled nearly two years later. All the data accumulated by John Stevens led him to the same conclusion ultimately determined by the French engineers—building a sea-level canal at Panama would be very difficult, if not impossible. He estimated that a lock-and-dam canal could be completed in nine years, possibly eight. A sea-level canal would require a minimum of 18 years. He convinced Theodore Roosevelt of this, and he thought the matter was settled.

This, however, was not the case. In spite of the French experience, the lock-and-dam versus sea-level debate was still going strong in the U.S. Senate in 1906. Showing much of the same diligence and intelligence one might expect today, the Senate, with responsibility to oversee the canal project, took a vote on how to build the canal. By one vote, they approved a sea-level canal. One unavoidable observation from study of past projects is that things really do not change very much over time, and politics is rarely driven by logic.

John Stevens had just returned to Panama from Washington in 1906, and although he was quite busy with the project, he turned around and sailed back to the United States. He met extensively with members of both the U.S. House of Representatives and the Senate. He patiently explained the challenges of a sea-level canal in a rain forest with flooding rivers. He developed data, drew maps, and generally described to anyone who would listen all the reasons why the canal could not be built at sea level. As was true earlier for the French, the main obstacle was the flooding of the Chagres River, which flows north into the Gulf of Mexico parallel to the proposed canal for nearly half of its route.

Stevens spent a lot of time with one ally, Senator Philander Knox. Senator Knox was from Pennsylvania—specifically, he was from Pittsburgh, Pennsylvania. Stevens worked with Knox on a speech in which the senator described in detail why the canal must be constructed with dams and locks. By all reports, it was an excellent speech, delivered with great eloquence and vigor. (It was probably not entirely a coincidence that a sea-level canal required none of the locks, steel doors, and other hardware that would come from Senator Knox's friends in the foremost steel-producing city in the Americas.)

Despite of all this, there were still 31 senators who voted for a sea-level canal. Fortunately for the project and for Stevens, there were 37 senators who were paying attention, and the design Stevens recommended was approved.

It had taken him more than a year, but finally John Stevens had his plan completed and approved. Defending the feasible plan required all of his data, principled negotiation, and a great deal of perseverance, but he ultimately avoided the costly disaster of a second impossible canal project at Panama.

Risk-based Replanning

Project monitoring and prompt responses when necessary were among the main differences between the first effort to construct the Panama Canal and the second one. No project proceeds exactly as planned, and the U.S. canal project was no exception. It was ultimately successful because the managers and workers revised their plans to effectively deal with problems as they emerged.

As the work at Panama continued, for example, it seemed that the more they dug, the more there was to dig. Mudslides were frequent, and between 1906 and 1913 the total estimates for excavation more than doubled. The response to this problem was not terribly elegant, but it was effective. Following the report of a particularly enormous mudslide in the Culebra Cut, George Goethals remarked, "Hell, dig it out again." They had to, many times. Some risks are managed primarily through persistence and perseverance.

As time passed, a number of factors not known at the start of the project came into focus. By 1908, it became clear that new materials, including the steels to be used on the canal, were making possible the construction of much larger ships. Goethals made two significant design changes as a result of this. The first was to commit to a wider excavation of the Culebra Cut, increasing it to nearly 100 meters (from 200 feet to 300 feet) to accommodate ships wider than 30 meters sailing in each direction. Although this represented much additional digging, it also made the tasks of ongoing maintenance and dredging a little easier.

The second change was to the size of the locks. Based on Goethal's estimates of the size of future ocean-going ships, the locks were enlarged to be 110 feet wide and 1000 feet long. Although conversion to metric units of these dimensions is trivial, few do it, as this somewhat arbitrary choice became the single most important factor in twentieth-century ship building. These dimensions are the exact size of the rectangular-hulled PANAMAX ships, the largest ships that can transit the canal. Apart from oil supertankers (which are generally designed for use on a single-ocean, point-to-point route), very few ships are built any bigger than a Panama Canal lock.

In addition to making the locks larger, Goethals made another change to them. All the water used to operate the canal flows by gravity. Locks are filled from the man-made lakes above them and then emptied into the ocean. During the rainy season, this works well. In the drier parts of the year, the depth of the lakes falls, and the water level in the cut connecting them could fall too low to permit ocean-going ships to pass. To save water, Goethals redesigned each of the twelve locks with multiple sets of doors, enabling smaller ships to lock through using a much smaller volume of water.

One additional significant change was adopted midproject, primarily for security reasons. At the start of the twentieth century, the global political situation, particularly in Europe, was increasingly unstable. The geography of Panama has a long, gradual slope from the central ridge north on the Atlantic side, and a much shorter, steeper slope on the south, facing the Pacific. On the steeper Pacific slopes, the locks in the original plan were visible from the water, and Goethals, a military man, feared that the canal might be closed down by projectiles fired from an offshore warship. To avoid this, he moved the Pacific locks further inland. The change actually made the engineering somewhat easier, as the new plan took better advantage of the more level land farther up the slope.

George Goethals managed risk through scrupulous management of all changes, insisting throughout his tenure that "everything must be written down." Once the plan was set, the debating stopped, and all the effort went to execution.

Completion

On August 15, 1914, the first sea-going vessel crossed Panama, and the Panama Canal opened all the way through. This huge accomplishment was reported far and wide as the biggest news of the day. The attention lasted only a short time, though, as soon World War I broke out in Europe and quickly overshadowed the canal story.

In retrospect: The 80-kilometer (50-mile) lock-and-dam canal was completed, slightly more than ten years after the congressional act that initiated the work. About 5,000 additional lives were lost finishing the U.S. project. Some died from disease, but most of the loss of life was from explosives (making the total death toll as high as 30,000, including those who died in the 1800s). The canal opened six months ahead of the schedule set earlier by John Stevens, despite all the difficulties and changes. Even more remarkable, it finished at a cost US$23 million less than the budget (US$352 million had been approved). The total cost for construction was over US$600 million, including the cost of the French project. If this is not the only U.S. government project ever to finish both early and under budget, it is certainly the largest one to do so.

Most of the credit goes to George Washington Goethals. Although he acknowledged his debt to John Stevens, nearly all the work was accomplished while Goethals was Chief Engineer. After the opening of the canal, Goethals remained in Panama as governor of the Canal Zone, to oversee its early operation and deal with any problems. His thoughts on completion of the work at Panama, delivered in March of 1915, were:

We are gathered here tonight, not in the hope of something to be accomplished, but of actual accomplishment: the two oceans have been united. The [mud]slides hinder and prevent navigation for a few days, but in time they will be removed. The construction of the Canal means but little in comparison with its coming usefulness to the world and what it will bring about. Its completion is due to the brain and brawn of the men who are gathered here—men who have served loyally and well; and no commander in the world ever had a more faithful force than that which worked with me in building the Panama Canal.

If you were asked to name a famous engineer, Goethals would be an excellent choice. While there are other engineers who have become famous as astronauts, politicians, and multimillionaires, Goethals is famous for engineering. His accomplishments in addition to the canal are substantial, and he remains a significant influence in civil engineering to this day. The lessons learned from this project are thoroughly documented (as with all projects undertaken by the U.S. Army Corps of Engineers). They serve as the foundation not only for the subsequent civil engineering projects of the twentieth century but also for much of what is now recognized as modern project management.

The Next Project

Projects have a beginning and an end, but they are generally part of a continuum of activities stretching back into the past and forward into the future. For the remainder of the twentieth century, the basic operation of the Panama Canal was largely unchanged, except for ongoing maintenance, widening of the cut, and a new dam built upstream in the 1930s to ensure continuous operation through the drier seasons. A plan in the 1950s to replace the canal with Ferdinand de Lesseps's imagined sea-level canal using thermonuclear bombs for the excavation was taken seriously for a time, but (fortunately) it was shelved.

As the twenty-first century begins, so does a new era for the canal. Following the 1999 turnover by the United States, the canal is now operated by Panama. It remains a vital link in world shipping, but to ensure this into the future, the first major operational change in the nearly 90-year life of the canal is now in the planning stages—adding a third transit through the isthmus. A new set of locks, parallel to the existing locks on the Atlantic and Pacific sides of the canal, are proposed that will be nearly twice as wide, 40 percent longer, and 25 percent deeper. This new route will permit transit of larger ships in addition to quicker transit for the PANAMAX freighters currently using the canal. The new locks will hold nearly four times the volume of water required to operate the current locks, and their use will require massive dredging to allow the existing lakes to supply enough water. The magnitude of this overall effort is comparable to the original project, so it will be interesting to see which of the earlier projects the new endeavor will most resemble.