The Panama Canal[1]

Early Routes Across the Isthmus

Columbus, sailing west in hopes of opening a trade route between Europe and Asia, instead ran into the Americas. While promising in terms of future development and precious metals, the Americas were not accepted as the limits of Spanish interest. The ultimate goal remained opening up a trade route to the civilizations of Asia.

Balboa, in 1516, was the first to establish a freight route across the isthmus. Having "discovered" the Pacific Ocean, with help from the local indians, he of course wanted to continue his explorations. To do this, he needed to build ships on the Pacific side of the isthmus, and the trees required for the task grew only on the Atlantic side.

> "The terribly onerous labor of collecting the material and carrying it on their backs to its destination was imposed upon the indians, of whom thousands were gathered together for the purpose, and impelled to the unaccustomed work by the merciless severity of their taskmasters. Many months were consumed in this grim struggle for a passage of the Isthmus, which, in many respects, foreshadowed the endeavors of the modern successors of these hardy pioneers. Hundreds of the wretched aborigines, Las Casas says their number fell little short of two thousand, lost their lives in the undertaking, but it succeeded, and four brigantines were carried piecemeal from sea to sea and put together on the Pacific coast." [Marshall, p. 19]

Balboa's efforts were, for him at least, for naught; before he could depart on his expedition, he was tried, convicted, and executed on trumped-up charges by the jealous Spanish governor of the region. While exploration by sea was put on hold, the need for a "permanent highway to take the place of the Indian trails which were poorly adapted to the traffic which had now begun to move over them became apparent" [Marshall, pp. 19-20]. With great difficulty, a paved road wide enough for two carts was constructed in 1521 linking Old Panama on the Pacific with Nombre de Dios on the Atlantic. After about 10 years, the use of the route was modified to an intermodal route, with light sailing vessels leaving from Nombre de Dios and sailing up the Chagres in order to meet up with the road. By the end of the 16th century, the Atlantic terminus of the cross-isthmus road was shifted to Porto Bello. By then, this road was the "richest highway in the world", as it was the critical link between the Atlantic and Old Panama (the "most important Spanish City in the New World"), the mines of Peru, and the major regional fairs in Cartagena and Porto Bello. [Marshall, p.20-21].

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[1] This case study was prepared by Carl D. Martland, Senior Research Associate & Lecturer, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. It is intended to serve as the basis for class discussion concerning project development and evaluation.

The Spanish continued to look for an all water route to the orient. In 1519, Magellen found the southern route to the Pacific, passing through the Straits of Tierra del Fuego. In 1522, using Balboa's vessels, Gil Gonzales sailed north, looking for a waterway, and eventually found Lake Nicaragua; in 1529, Diego Machuca explored the Lake and, with difficulty, navigated the San Juan River from the Lake to the Atlantic. Over the next century, this became an important commercial route for "vessels making ports in Spain, the West Indies and South America ... for more than a hundred years, a constant stream of gold, pearls, and other products of Spain's island possessions flowed across the Isthmus" [Marshall, p. 19]. About this time Cortes established a transcontinental trade route across Mexico, from the mouth of the Coatzacoalcos River to the port of Tehuantepec on the Pacific, which was used as a trade route between Spain and the Americas as well as a link to the Phillipines.

Military considerations put plans for a water route on hold. Philip the Second feared that a water route across the isthmus would simply give enemies easy access to Spain's new possessions. This policy lasted tor two centuries. In the late 1700s, the possibility of a canal along the Cortes route was investigated by Manuel Galisteo. Although his conclusion was unfavorable, Britsh engineers accompanying Galisteo felt the project was feasible. When war broke out with Spain, the British sent Captain Horatio Nelson to the region, who viewed his mission as follows:

> "In order to give facility to the great object of the government I intend to possess the Lake of Nicaragua, which for the present, may be looked upon as the inland Gibraltar of Spanish America. As it commands the only water pass between the oceans, its situation must ever render it a principal post to insure passage to the Southern Ocean, and by our possession of it, Spanish America is divided in two." [Marshall, p. 25]

Nelson and his men indeed grabbed control of Lake Nicaragua, but climate and illness forced them out, and Spain retained control of the "canal region" at the beginning of the 18th century. New investigations by Humboldt generated interest in a canal, and in 1814 Spain passed legislation authorizing the construction of a canal. Before any work could begin, revolutions in South and Central America overthrew the Spanish dominance and

> "opened up new possibilities in connection with the much-mooted question of a waterway and claimed the attention of capitalists and statesmen of all the commercial nations. From this time the matter is taken up with definiteness of purpose and never allowed to rest." [Marshall, p. 27]

The United States officially became interested in 1825, when Secretary of State Henry Clay entered into negotiations with the Republic of Central America for building a canal across Nicaragua "the execution of which ... will form a great epoch in the commercial affairs of the whole world." [Marshall, p. 28]

In 1827, the Colombia commissioned J.A. Lloyd to study possible rail and water routes across the Isthmus of Panama. Lloyd considered plans for a canal to be premature and

instead recommended an intermodal route combining water and rail to take the place of inadequate roads.

In 1838, a French company obtained a concession from what was now New Granada to construct highways, canals, or railroads from Panama to the Atlantic, by any feasible route. The pressure and interest was growing, but the difficulties were not yet well understood, and the costs of construction were greatly underestimated by all parties involved.

From the perspective of the United States, the strategic importance of the Isthmus changed immensely when California was acquired in 1848 as a result of the war with Mexico:

> "The requirements of travel and commerce demanded better methods of transportation between the Eastern States and the Pacific coast, but there were other reasons of a more public character for bringing these sections into closer communication. The establishment and maintenance of army posts and naval stations in the newly acquired and settled regions in the Far West, the extension of mail facilities to the inhabitants, and the discharge of other governmental functions, all required a connection in the shortest time and at the least distance that was possible and practicable. The importance of this connection was so manifest that the Government was aroused to actions before all the enumerated causes had come into operation, and negotiations were entered into with the Republic of New Granada to secure a right of transit across the Isthmus of Panama" [Report of the Isthmian Canal Commission. Washington, 1899-1901, cited in Marshall, p. 34].

A treaty was ratified with New Granada in 1848 for the Panama route in 1848. In 1849, a treaty was ratified with Nicaragua to allow construction of railroads, highways, or canals across Nicaragua. For many years thereafter, it appeared most likely that the US, if it did build a canal, would choose the Nicarguan route.

The discovery of gold in California vastly increased the demand for transportation across the Isthmus, as thousands of "forty-niners" flocked to the gold fields. This led to the construction of the Panama Railroad, as discussed in the next section.

The Panama Railroad

The idea of a railroad across Panama remained just that until the gold rush raised the possibilities of profits to much higher levels. After earlier concessions expired without producing any construction, New Granada granted the railway concession to the Panama Railroad Company, which was incorporated in 1849 with strong financial backing from Wall Street. The concession gave the company a railroad monopoly across the isthmus and allowed it to sell its assets at a fair price to any company that was authorized to build a canal (since a canal, once built, would likely destroy the railroad, both financially and literally).

The benefits of a railroad were clear. For passengers, the railroad, once built, would cut the transit time across the isthmus from a hazardous 5 to 10 days to a relatively luxurious couple of hours. For freight, the time savings were even greater, as months could be saved by not going around Cape Horn. For a trip from New York to San Francisco, the all water route is 13,000 miles, whereas the intermodal route via the Panama Railroad would be only 5,000 miles, a savings of 8,000 miles.

The engineering work for the railroad began in 1849, and construction was estimated to require two years and a cost of less than $2 million [McCullough, p. 34]. In fact, the first train operated across the 48-mile broad guage (5 feet) line in 1855 and the construction cost was more than $8 million, six times the initial estimates. In addition, the railroad acknowledged more than 1,200 fatalities in the work force, which averaged 5,000 men over the five years of construction. More likely, there were more than 6,000 fatalities from disease [McCullough, p. 37].

The railroad was a financial success, with profits of 12 to 22% per year, i.e. $1 to $2 million annually. The railroad also reshaped the economic geography of Panama, as Colon, at the terminus of the railroad, replaced Porto Bello as the major Atlantic port. The financial success was to be expected given the potential for the railroad to capture the lion's share of the benefits of not having to ship around South America or to trek through the jungles of Panama. Passengers were quite happy to pay the fare of $25, and there were 40,000 passengers per year from 1856 to 1966 [McCullough, p. 35-36]. Shippers were also willing to pay a bill that might be nearly as much per ton:

> "With the opening of the railroad, a large traffic across the isthmus sprang into existence and grew rapidly with the advance of time. The products of Asia and the countries upon the Pacific coast were carried [on the railroad] from Panama to Colon, there to be distributed amongst steamships making the ports of Europe, Canada, the Unitied States and the West Indies. Moving in the reverse direction, goods from these countries reached, by the same transisthmian route, South and Central American and San Francisco. From the last named port, reshipment was made to the Pacific islands and points on the Asian mainland. A number of steamship lines made regular calls at the terminal ports of the railroad. The line occupied a commanding position as the essential link in this chain of traffic, and took full advantage of the fact. Its charges were exorbitant and its profits enormous for many years. Its rates were based on, in general, fifty per cent of the through tariff. For instance, of the total cost of shipping goods from New York to Valparaiso [in Chile], one half represented the charge of the railroad company for its share of the carriage. For many years the road carried enormous quantities of coffee to Europe. The through rate was about thirty dollars per ton. The railroad company received fifteen dollars and the two steamship companies that handled the goods divided a similar sum." [Marshall, pp. 52-53]

In the first 6 years of operation, the Panama Railroad had cumulative profits of more than $7 million, nearly recouping the entire construction cost. At one point, the stock price of the Panama Railroad Company reached $295 per share, the highest on the NY

Stock Exchange for a market valuation of $21 million and an indication to potential investors of the financial possibilities of a transcontinental connection [McCullough, p. 35-36].

In 1879, the railroad was offered for sale to the [French] Panama Canal Company for $14 million; 6/7 of the stock of the company was eventually sold to the Panama Canal Company for $18.6 million [Marshall, p. 109].

When the United States took over the construction of the Canal from the French in 1904, it acquired the railroad as well. Shippers took the change in ownership as an opportunity to challenge the monopolistic pricing practices of the railroad. For example, the railroad had a contract that gave the Pacific Mail Steamship Company the exclusive right to issue through bills of lading from San Francisco to New York; all other steamship lines would have to pay full fare for the local rail move. When the US took over, the monopolistic rates were replaced with rates designed only to provide a fair rate of return over costs [Marshall, pp. 55-56]. This ended the period of independent prosperity for the railroad.

However, the Panama Railroad's finest hour was yet to come. To construct the canal required the extensive use of the railroad, but the railroad first had to be moved, since much of it would otherwise be flooded by the creation of Lake Gatun, a critical step in the construction. The cost of the new, double track line was $8.9 million, i.e. roughly the same as the cost of the original line. During the height of the canal construction, the line handled 700 to 800 dirt trains daily, each consisting of a locomotive and 18 flat cars with a total load of 500 tons. The peak year was 1910, when the line moved approximately 300 million tons of freight, a truly phenomenal amount that is roughly 20% of the record levels of tonnage handled by the entire US rail system (during World War II and again in the late 1990s) [AAR, Railway Facts]. Despite tremendous technological advances in both track and equipment, the highest density lines in US [and in the world] carry less than half that amount of tonnage at the end of the 20th century [AAR, Railway Facts].

The French Effort

The first serious effort to construct a transisthmian canal was initiated by the Panama Canal Company, a French company headed by Ferdinand de Lesseps, the man who had conceived, organized, and completed the construction of the Suez Canal. A number of engineering conferences had been held to debate the route, the nature of the canal, and the resources required. Panama was the route favored by de Lesseps, who also insisted on a sea-level canal. The construction time for and the cost of constructing the canal were variously estimated at 2 years and $100 million (by a contractor eager to do the job), 8 years and $168 million by a national technical commission, to 12 years and $214 million by the Paris Congress. De Lesseps, in promoting the project, chose a figure of $131 million. Note that the canal was clearly going to be much more expensive than the railroad, since all of these estimates were on the order of 100 times the initial estimates of constructing the railroad that was eventually built for $8 million.

De Lesseps estimated the first year's traffic as 6 million tons, which would assure revenue of $18 million (at $3 per ton). Since a sea-level canal would have low operating, most of the toll revenue would be expected to be profit. Hence, according to the company's statements, the project would return approximately 10-15% once it opened for business.

Writing in 1913, just before the canal finally opened, Marshall (and the whole world) knew that the cost estimates were way too low. He also stated that the revenue estimate "was claimed to be a very conservative assumption, whereas, it was in reality almost beyond the possibility of realization" [p. 98]. Given that the railroad freight charge was as much as $15 per ton, a price of $3 per ton might well have seemed reasonable at the time. However, by 1913, with the US running the railroad, the rates were no longer so extravagant and, with larger ships operating, the prices of ocean transport had also fallen. Marshall may also have been concerned with the projected volume of traffic. (In actual fact, the canal handled 4.9 million long tons of cargo and earned revenues of $4.4 million in its first full year of operation in 1915; by 1923, with cargo of nearly 20 million tons, revenues reached $17.5 million [Office of Executive Planning, Panama Canal Commission, Historical Reports - Report: Panama Canal Traffic - Oceangoing Commerce]).

The canal was viewed as a tremendous financial opportunity, and the effort was therefore undertaken by the private sector. The Panama Canal Company was formed in 1879 with an initial capitalization goal of $80 million and, given the general excitement, double that was raised very quickly [Marshall, p. 99].

Construction began in 1883, and troubles were almost immediately encountered. The amount of excavation required was more than expected, the soil conditions were much softer and more instable than anticipated, and the 20-foot difference in tides between the Pacific and the Atlantic was recognized as a major problem. Yellow fever and malaria took a fearful toll among the workers and their families, and the project took on the aspect of a military campaign.

Nevertheless, de Lesseps still expected the canal to be completed by 1888. His engineers were more realistic, and they recommended that a lock canal be built to reduce the need for excavation. De Lesseps, however, refused to break his promise for a sea-level canal. Marshall emphasizes that this particular dispute concerned matters of financial rather than engineering feasibility:

> "The point of their decision was whether a sea level canal could be constructed at a cost and in such time as to make its after operation a profitable business for the shareholders. Time, of course, is a great factor in the cost of an operation involving hundreds of millions. Interest increases at an enormous rate during the later years. Therefore, considerations which would preclude the pursuit of a project solely contemplating commercial results might not be of sufficient weight to deter a government from following the same lines. ... Even though the operation of the canal should fail to return any interest upon the money invested, the Government might

> well consider itself fully compensated for the outlay by the political advantages secured, the great savings in the movements of warships, and other desiderata." [Marshall, p. 104].

The labor force was nearly 10,000 men by 1887; the standard wage was $1.50 per day for about 20 days per month [Marshall, p. 105]. The payroll for laborers was therefore on the order of $5 million per year. Another 1,500 or so company employees added several more million to the payroll, and costs and transportation of machinery averaged several million per year. The big problem, however, was that the costs were rising and the possibility of ever making a profit was disappearing. By 1989, the company had raised (and spent) $265 million and was looking for more than $100 million more. Interest charges were already $16 million per year, and it was apparent that they would rise to more than $30 million by the time the canal was opened (assuming that it could be completed). Since revenues were projected to be only $18 million, the prospects were nil, and this was evident to everyone with any money to invest. A final effort to raise $160 million in "lottery bonds" that would provide 4% interest plus participation in semimonthly drawings for cash prizes was approved by the government, but only about $60 million was raised. This was the last hope for the French effort, and the Panama Canal Company went into bankruptcy in 1889.

At this point, if the canal project were to be terminated, the company and its shareholders would lose everything. Since the work completed at that time was valued at about $100 million, a major effort was made to reorganize the effort in order at least to salvage this value. Colombia, which also stood to gain from the construction of the canal, was also very anxious for work to proceed. The result was that the a new company, the New Panama Canal Company, emerged from the chaos of the old and was given an extension until 1904 to complete the canal.

At this time extensive engineering surveys were conducted by a commission established to review the status of the canal. The commission believed that "a lock canal might be completed in eight years at a further cost of $100 million." The New Panama Canal Company therefore studied how such a canal might be built.

They also saw another way to escape from their problems: sell their concession, equipment, and the completed portions of the canal to the United States, which at that time was pursuing the possibility of digging a canal in Nicaragua. After several years of negotiations and study, the New Panama Canal Company offered to sell everything to the US for $109 million. The Isthmian Canal Commission, in its report to President Roosevelt, set the value of the property at only $40 million and concluded that the Nicaragua route would actually be the "most practical and feasible route". Since there was only one possible buyer for the property, the New Panama Canal Company, in a panic to salvage something, quickly reduced its asking price to $40 million offer. In turn, the Isthmian Canal Commission revised its opinion concerning the route on the grounds that Panama was preferable at thelower price.

This deal cleared the way for the US to take over the construction of the canal, although not before a good deal of political theatre. Suffice it to say that Colombia attempted to raise the annual fee that it would collect, that the US balked, and that Panamanian citizens, fearful of losing the canal to Nicaragua, declared the independence of Panama. McCullough describes the intrigue in absorbing detail; Joseph Conrad describes the emotions of times in his great novel "Nostromo," which was modelled on these events.

The US Effort

"To Europeans, the benefits of and advantages of the proposed canal are great; to Americans they are incalculable." U.S. Grant, President of the United States

When the US took over, they had to deal with several major design issues related to the cost, capacity, and performance of the canal:

- Sea level vs. a lock canal
- The number and height of the locks
- The length and the width of the locks
- The height of the canal above sea level and the size of the lake

They also had to deal with the tropical illnesses. Fortunately, mosquitos had been identified as the transmitters of malaria and yellow fever, so it was possible to formulate and implement a strategy for eliminating mosquitos as a way of controlling disease. That fascinating story is covered by McCullough; suffice it to say that first priority was given to eradicating the mosquito within the Canal Zone, and the diseases were successfully eliminated.

Sea level vs. a lock canal

A sea level canal would have the advantage of lower lock cost and easier operations, but it would require more excavation. Since the tides on the Pacific vary by 20 feet from high to low, a tidal lock would be needed on that end of the canal even for the sea level route (otherwise tidal currents would be too strong to safely operate large ships through the canal). A lock canal would reduce the excavation costs and reduce the time required to open the canal to operations. Like de Lesseps, most people wanted a sea level canal, if it were reasonably possible to construct one:

> "I hope that ultimately it will prove feasible to build a sea-level canal. Such a canal would undoubtedly be best in the end, if feasible, and I feel that one of the chief advantages of the Panama Route is that ultimately a sea-level canal will be a possibility. But, while paying heed to the ideal perfectibility of the scheme from an engineer's standpoint, remember the need of having a plan which shall provide for the immediate building of the canal on the safest terms and in the shortest possible time.

> "If to build a sea-level canal will but slightly increase the risk, then of course, it is preferable. But if to adopt a plan of a sea-level canal means to incur hazard, and to insure indefinite delay, then it is not preferable. If the advantages and disadvantages are closely balanced I expect you to say so.
>
> "... Two of the prime considerations to be kept steadily in mind are: 1. The utmost practicable speed of construction. 2. Practical certainty that the plan proposed will be feasible; that it can be carried out with the minimum risk."
>
> President Roosevelt's instructions to the International Board of Consulting Engineers that was assembled to consider the principal problems in construction a canal, September, 1905 [quoted by Marshall, p. 134]

The number and height of locks

The commission recommended a sea-level canal, but the American members filed a minority report recommending a lock canal that would reach 85 feet above sea level. Congress accepted the minority report, and that was the basis for what was built.

The number and height of locks represents a balance among lock technology, operating costs, and construction costs. The height of the lock chamber and the mitre gates must be several feet higher than the draft of the largest ships (close to 40 feet) plus the height of the lift plus several feet of water under the ship plus a foot or two above water level when full. For an 85 foot lift, this would require two locks with a lift of 42.5 feet each or three with a lift of 27.4 feet each; even the smaller lift would be higher than any other locks yet constructed, and the required chambers and gates would be about 80 feet high. A three lock system was selected for each end of the canal.

The length and width of the locks

The goal for the canal was to handle the largest ships planned as of that time, which were in fact battleships. The original dimensions of the lock chambers were to be 900 feet long by 95 feet wide (by 81 feet deep) but the Navy requested an increase to 1000 feet long by 110 feet in order to allow for larger ships in the future. There was a debate about whether or not to go to the larger size. Colonel Goethals, in charge of the canal construction, advanced the case for staying with a 100 foot beam:

> "The present lock designs provide ingtermediate gates dividing the locks into lengths of 600 and 400 feet. About 98 per cent of all ships, including the largest battleships now building, can be passed through the 600-foot lengths, and the total lock length will accommodate the largest commercial vessels now building, which, I believe are 1,000 feet long and 88 feet beam. It is true that ships may increase in size so as to make the present locks obsolete, but the largest ships now afloat cannot navigate the Suez Canal, nor the proposed sea level canal at Panama. It must also be remembered that the commerce of the work is carried by the medium-sized vessels, the length of

> only one of the many ships using the Suez Canal being greater than 600 feet." [quoted in Marshall, p. 186]

Marshall, who was writing in 1913, was happy to report that Goethals was overruled and the lock dimensions were set at 1000 by 110 feet:

> "Our new battleships have a beam of 97 feet and upwards, which will leave a clearance in the lock chambers of less than 13 feet in all, or about 6 feet on either side. Commercial vessels now built, and others whose keels have been laid, have a beam of 96 feet, so that it is quite possible that the locks may prove to be too narrow before they are found too short." [Marshall, p. 186]

Water Requirements

The height of the canal above sea-level and the size of the locks represent a balance between the availability of water and the size of ships that can be handled. Larger locks require more water, but they can handle larger ships. If the canal is higher, and the chambers are deeper, then more water is also required.

A canal requires a source of water sufficient to operate the gates year round. If there is a distinct dry season, then the lake ideally would have enough reserve capacity to operate throughout the dry season without affecting operations. Given the size of the lock chambers, a great deal of water is used for each lockage. The basic requirements are that the total water lost through lockages be less than the average annual inflow to the lake and that the surplus water in the system be sufficient at the beginning of the dry season to last until the rains return.

A height of 85 feet above sea level was selected for Lake Gatun, the 164 square mile lake that was created by flooding the Chagres River. This lake impounded water from a basin of 1,320 square miles that "enjoyed" extremely heavy tropical rains from early may through the beginning of December. The amount of water was quite considerable. In the 22 years before the opening of the canal, the outflow of the river ranged from a low of 132 billion cubic feet in 1912 to a high of 360 billion cubic feet in 1910, nearly double the 183 million cubic feet contained by the lake when full. Marshall used the 1912 season to illustrate the adequacy of the lake for supporting the canal operations. If Lake Gatun enterered the rainy season on December 1 with an elevation of 87 feet and operated with 48 lockages per day, then the lake level would decline to 79.5 feet by May 7th, when the rains returned. With this water level, there would be 39 feet of water in the cut, which would provide sufficient depth for navigation (for the ships of that time). Allowing for evaporation and seepage, there would still be enough water for 41 lockages a day, which was more than could actually be done because of the time required per vessel.

The width of the Cut

The width of the cut was originally set at 200 feet, but this would not allow enough room for two large ships to pass. The width was therefore increased to 300 feet. A wider cut required considerably more excavation, but also increased the capacity of the canal.

Construction Cost

The construction of the Panama Canal was the largest project undertaken by the US up until that time. After the US had been at work for 3 years, it was estimated that the cost would be $375 million, including original payments of $10 million to Panama and $40 million to the French company [McCullough, p. 610]. This proved to be accurate, as the actual construction cost was $352 million for the US portion of the work (and a total of $639 million for the French and American efforts).

The loss of life associated with the construction was staggering. Disease and accidents claimed 5,609 lives between 1904 and 1914, but this was far better than the French experience, as they lost approximately 20,000 people.

If the French companies and their prospective stockholders had understood the financial and the human costs, they never would have been able to raise the money to begin. If the US Congress had realized the magnitude of the effort in 1904, they might well have balked as well [McCullough, p. 610].

It is an irony of history that the first vessel went through the canal on August 3, 1914, the day that World War I began. Though completed 6 months ahead of schedule, it would be 10 years before traffic would grow to the expected levels of 5,000 ships per year. Toll revenues reached $27 million in 1929 and 1930, but did not reach these level again until 1953, because of the effects of depression and another world war.

The congress required the Panama Canal to operate on a break-even basis, i.e. it must cover both operating and capital costs from tolls. This prevents the Commission from incurring debt or from achieving exorbitant profits. It also means that there was no attempt to recover the capital costs of constructing the canal. If the Canal had been fincanced through private sources at 5%, the interest costs during the 10-year construction period would have added well over $100 million to the initial cost and the carrying charges would have been on the order of $25 million annually thereafter. Given the tredmendous savings in distance, it is quite possible that tolls could have been raised to cover this cost during good times, but it is also quite likely that the Canal would have gone bankrupt during the wars or the depression.

During World War I, the Canal played no strategic military role, as the first flotilla of warships to transit the canal was composed of ships returning home after the war. In World War II, the canal played a major role, as it allowed rapid deployment of ships from the Atlantic to the Pacific theatre of operations.

Late 20th Century Issues

In 1996, the Canal handled 13,536 ocean-going commercial vessels carrying 198 million long tons of cargo and earned revenues of $483 million from tolls. While the average toll per ton remained less than the $3 projected by de Lesseps, the total tonnage and total revenue greatly exceeded his projections of 6 million and $18 million respectively. The cumulative toll revenue from the opening of the canal reached $9 billion by 1997.

Transfer of the Canal to Panama

The operation of the canal was transferred to Panama on December 31, 1999, culminating a 20-year transition period in which responsibility has been shifted from the US to Panama. In anticipation of the transfer, the Panama Canal Commission and the US Army Corps of Engineers conducted a thorough inspection of the canal and the locks. In general, the locks and the canal were believed to be in excellent condition, and programs were in place for maintenance and rehabilitation of the major components of the canal.

A greater concern was the capacity of the canal, both in terms of the size of ships that can fit through the locks and the number of ships that can be handled on a sustainable basis. In 1996, the canal handled a record-breaking 37.5 ocean-going ships per day, which caused the Canal Waters Time (the time from arrival at one end of the canal until departure from the other end) to rise from the target level of 24 hours to more than 30 hours. This increase in delay signaled potentially serious capacity problems for the canal.

Post-Panamax Ships

Aircraft carriers and oil tankers were the first ships that exceeded the dimensions of the locks. In the 1980s, a new class of containerships (Post-Panamax) was designed for use in trans-Pacific operations; to reduce the cost per container, these ships were built wider than the 110 feet that could go through the canal. Even larger ships were being planned for the future. Since container shipping was one of the fastest growing areas of commerce, the existence of a large number of Post-Panamax ships was a strategic concern for the canal.

Capacity of the Locks

The capacity of the locks is limited by the average time required to move a large ship through one chamber, which is about an hour, suggesting a maximum service rate of 2 vessels per hour (since there are two parrallel channels in each set of locks). Additional time is also required to position ships as they arrive at the locks and the locks must periodically be closed for routine inspections and maintenance, so the sustainable capacity drops to 37-38 vessels per day.

Some efficiencies can be gained in lockages by increasing the number and reliability of the specialized railroad locomotives that are used to guide ships through the locks. Several minutes can be lost in repositioning locomotives when several large ships are

going through simultaneously. The Panama Canal Commission therefore authorized $90 million to increase the fleet from 82 to 110 locomotives. [Spillway, 1996]

Capacity of the Gaillard Cut

The Gaillard Cut was originally a minimum of 91.5m wide for its entire 12 km length. Widening to 152m, begun in the 1930s and completed by the early 1970s, allowed unrestricted two-way traffic for almost all ships operating at that time. However, by the 1980s, a substantial and growing number of the vessels using the canal were Panamax ships that were too large and unwieldy and too valuable to risk passing in the Gaillard Cut or operating in the Cut after dark. It was necessary for fleets of these large ships to operate single file through this 9-mile stretch during the daylight. This complicated scheduling and restricts capacity of the canal.

A widening program was begun during the mid-1990s and initially scheduled for completion by 2005. At a cost of $200 million, this program would increase the Cut to 192m in straight sections and up to 222m in curves in order to allow bi-directional operation of Panamax vessels. The program was spread out over so many years in order to allow the work to be done largely with the existing workforce and equipment. When the number of Panamax vessels grew rapidly during the mid-1990s, the capacity problem became more critical, and the program was accelerated so that it could be completed by 2002 and increase the capacity of the canal to approximately 42 ships per day. [Panama Canal Commission, 1996]

Capacity of the Locks

The capacity of the locks was limited by the availability of the specialized locomotives used to hold the ships in place as they go through the locks. As the system approaches capacity, the time required to wait for the locomotives to be repositioned becomes a factor in capacity. To relieve this problem, the Panama Canal Commission acquired additional locomotives.

System Control

A $20 million effort to develop a computerized scheduling system was expected to provide some improvements, but would only increase capacity by 1 ship per day.

Need for Substantial Increase in Capacity to Meet Demand

Additional locks or another canal will be needed to handle the demand projected for the first half of the next century. Even the pessimistic scenarios for growth foresee traffic growing to more than 50 vessels per day by 2050, which is at least 10 to 20% above what the above improvements will allow on a sustainable basis. A sea-level canal is estimated to cost on the order of $12 billion to construct, and it would have the same single file restrictions faced today by the Gaillard Cut. Hence this would only provide a 50%

increase in capacity. Adding a new set of locks, even a much larger set of locks, would increase capacity by 70% at a cost estimated at about $2 billion by the US Army Corps of Engineers.

Water Supply

In 1997/98, the canal experienced the lowest rainfall in its history. With rainfall a third less than normal, it was necessary to restrict operations to ships with a draft of 37 feet compared to the normal restriction of 39.5 feet. This was the first such restriction in 16 years. The water problem is viewed quite seriously because of the prospects for development that will either drain off water for other uses or eliminate wetlands that currently are able to store water during the rainy season. [Vogel, 1998]

It appears that the calculations cited above by Marshall were pretty much on the mark. He felt that there would be enough water for 41 lockages a day and still allow 39 feet of water in the cut for operations. Today, with perhaps 37 lockages, a problem has emerged and the solution has been to reduce draft to something closer to what Marshall anticipated (a ship with 39.5 feet draft will need perhaps 44 feet of water in the Cut; the estimates cited by Marshall assumed that 39 feet would be sufficient - with larger ships, the limits are reached sooner).

The 1997-98 drought also cast doubts on the feasibility of adding a third set of locks, unless some system is put in place to re-use the water. If the third set of locks is longer, wider, and deeper, as recommended, then the water requirements could be much greater and restrictions during dry periods would be much more likely.

References:

Marshall, Logan, *The Story of the Panama Canal*, L.T. Meyers, 1913

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Rohter, Larry, *Handoff in Panama: Hong Kong Was Just a Rehearsal*, The New York Times, July 13, 1997, p. 5

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Exhibit 1
Schematic of the Five Major Routes Considered for A Canal Linking the Atlantic and the Pacific

The five leading Central American canal routes that were considered during the 19th century. The two leading contenders were the route through Lake Nicaragua and the route across the Isthmus of Panama. The Panama route was much shorter than any of the other routes and the Lake Nicaragua route required less excavation.
[Source: McCullough, p. 465]

Exhibit 2
The Culebra Cut

A cross-section of what was originally called the Culebra Cut but is now known as the Gaillard Cut. Note that the original witdth planned by the French assumed that much steeper slopes would be feasible. The final width was much wider because of the unstable soil conditions.
[Source: McCullough, p. 465]

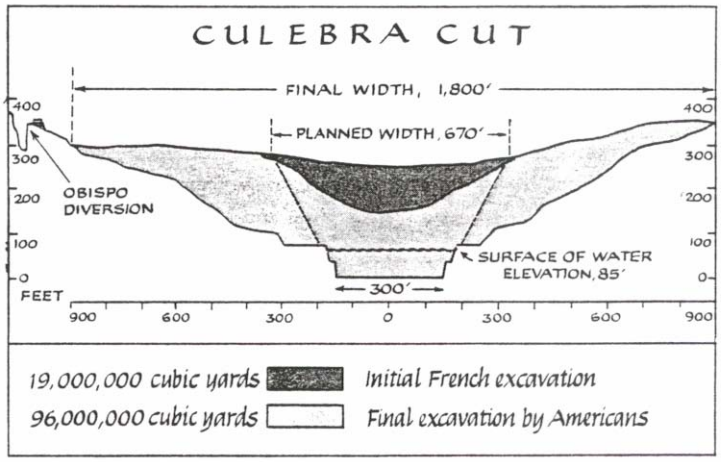
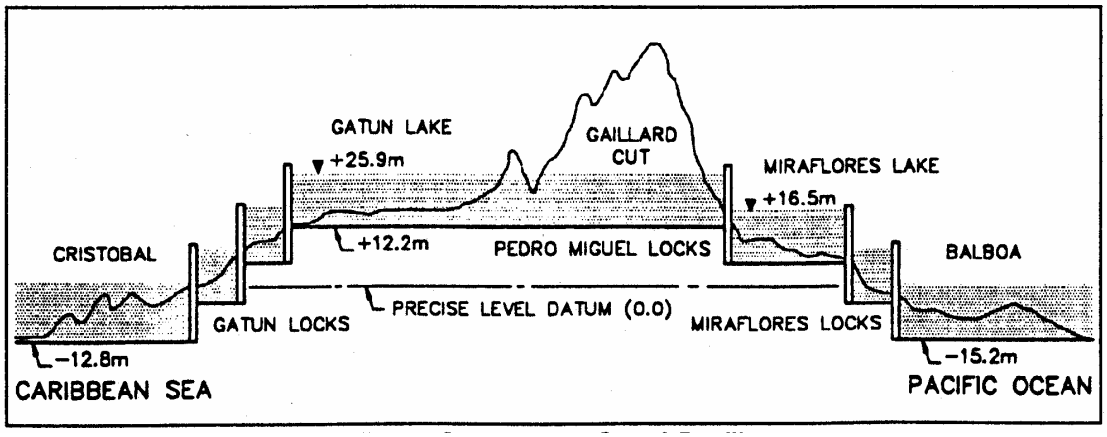


Exhibit 3
A Cross-Section of the Panama Canal
Three sets of locks on each side bring ships up to the level of Lake Gatun
Source: The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993



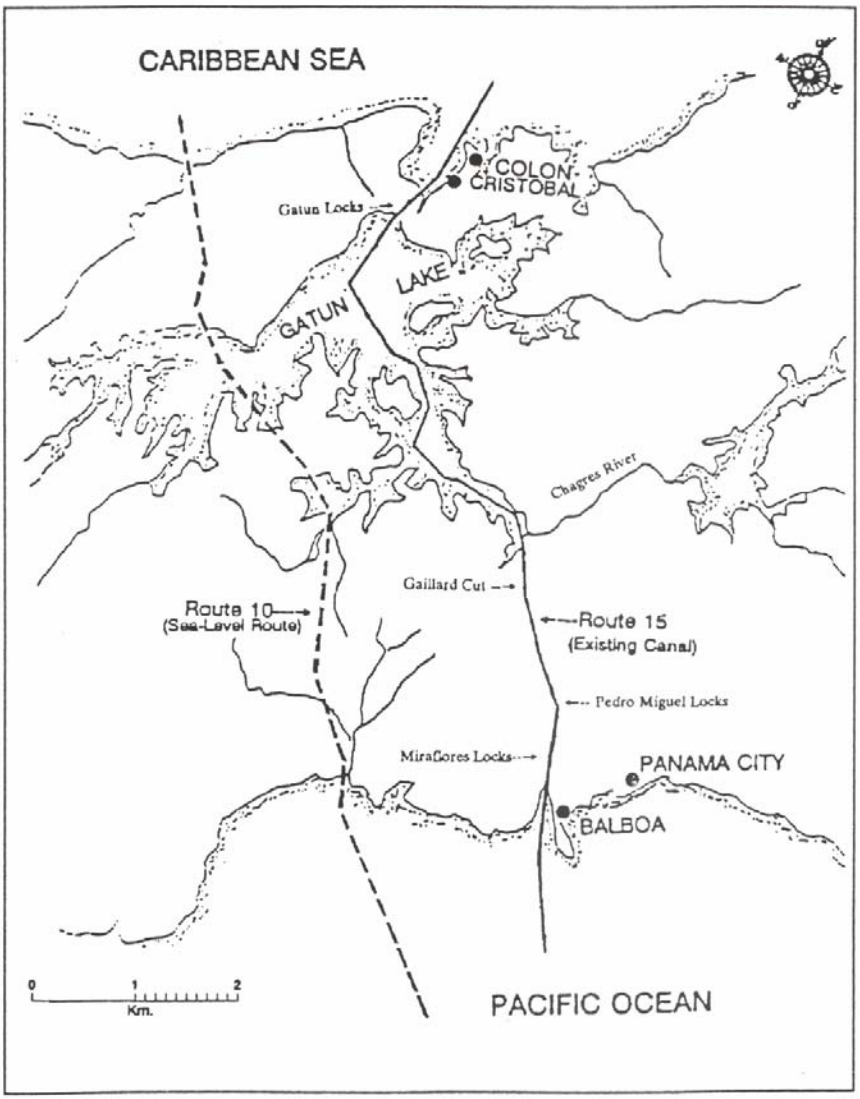


Exhibit 4
Map Showing Existing Route and Possible Sea-Level Route
(Source: The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993)

Exhibit 5
Oceangoing Traffic Through the Panama Canal, 1915 - 1996

(Source: Office of Executive Planning, Panama Canal Commission, Report TRA 1-3, Nov. 18,1996)

Fiscal Year	Transits/Year	Transits/Day	Long Tons of Cargo	Toll Revenue ($millions/yr)	Revenue./Ton
1915	1058	2.9	4.9	$4	$0.90
1920	2393	6.6	9.4	$9	$0.91
1925	4592	12.6	24.0	$21	$0.89
1930	6027	16.5	30.0	$27	$0.90
1935	5180	14.2	25.3	$23	$0.92
1940	5370	14.7	27.3	$21	$0.77
1945	1939	5.3	8.6	$7	$0.84
1950	5448	14.9	28.9	$24	$0.85
1955	7997	21.9	40.7	$34	$0.83
1960	10795	29.6	59.3	$51	$0.86
1965	11834	32.4	78.6	$65	$0.83
1970	13658	37.4	114.3	$95	$0.83
1975	13609	37.3	140.1	$142	$1.01
1980	13507	37.0	167.2	$292	$1.75
1985	11515	31.5	138.6	$299	$2.15
1990	11941	32.7	157.1	$354	$2.25
1994	12337	33.8	170.5	$417	$2.44
1995	13459	36.9	190.3	$460	$2.42
1996	13536	37.1	198.1	$483	$2.44

Exhibit 6
Panama Canal Traffic, by Commodity Group, 1994-1996

(Source: data prepared by Office of Executive Planning, Panama Canal Commission, May 8, 1997)

	Long Tons		
Commodity Group	**1996**	**1995**	**1994**
Grains	42.34	44.07	34.07
Petroleum and petroleum products	32.77	27.48	26.96
Containerized cargo	25.62	24.91	22.44
Nitrates, phosphates and potash	15.94	15.91	15.44
Coal and coke (excluding petroleum coke)	11.38	11.32	9.34
Ores and metals	11.52	10.76	10.1
Lumber and products, including pulp wood	11.03	10.71	9.47
Chemicals and petroleum chemicals	11.37	10.11	9.71
Manufactures of iron and steel	8.35	9.17	7.85
Canned and refrigerated foods	6.95	6.86	7
Minerals, miscellaneous	6.87	5.43	5.79
Other agricultural commodities	5.16	4.92	4.54
Machinery and equipment	1.93	2.14	2.05
All other	6.62	6.52	6.61
Total	198.07	190.3	170.54

Exhibit 7
Conceptual Alternatives to the Existing Canal
(Source: The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993)

	Existing Canal	**High-Rise Locks (a)**	**Low-Rise Locks (b)**	**Sea-Level (c)**
Vessel Size (dead wt. tons)	65 million	250 million	250 million	300 million
Rise (feet above sea level)	85	90	55	0
Number of lifts	3	2	1	0
Number of lanes	2	2	2	Half with 1; half with 2

Notes:

a. This option would follow the so-called "Route 15 and Third Lock" route (see Exhibit 8), with new locks utilizing taller gates so that only two lifts would be required; a somewhat deeper lake would necessitate a higher rise. (One variation of this option would be to keep the existing locks and add a third set that would be able to handle larger ships, thereby increasing capacity 70%.)
b. This option would require a new route, with only a single lift required.
c. This option would require an entirely new sea-level canal (see one possible route in Exhibit 4) that would still require locks because the great difference in tides would result in unacceptably rapid currents through the canal.

Exhibit 8
Schematics for the Existing and Proposed Locks
(Source: The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993)