# SYNTHETIC OPTIMIZATION IN ENGINEERING DECISIONS with Railway Examples

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# PREFACE

From the review of the past civil construction works in different countries, there were excellent and amazing master pieces with deeply touching spirit. Meanwhile, there also happened undesi-rable engineering projects. Among the latter, the failures might occur in any stage. But frequently, the greatest economic loss and harm to the society came from the planning stage. Some of the failures of decision in planning stage not only brought about waste of man-power, material and investment, but also caused long term disasters to the environment of great range for decades or even for centuries. These constructions caused by inadequate decisions in planning, once carried out, can hardly or never be restored in following stages, no matter how clever the detailed designers are, how the construction is effectively organized / accomplished and how skillful and diligent the managing leaders and maintanence engineers are.

Among the unsatisfactory planning decisions, the reasons of fault might be multi-sided: 1, incorrect estimation of service (traffic) amount, 2, ignorance of past experiences and lessons, domestic and foreign, 3, inco-ordination among the functional parts or systems, 4, conservative idea, including insufficient knowledge of scientific-technical advancement, 5, personal or dictatorial error etc.

There have been published books concerning theories, methodology, and specifications in various engineering fields for design, construction and maintanence as well as the mathematicoptimization in civil engineering system, but there scarcely appear literatures relating to co-ordination of inter-specialization planning decision, except in hydraulic engineering.

Since the extensive development of computer aided optimization method, the detailed design techniques of bridge and building structures, roadway alignment and other constructions according to certain preconceived decision have been satisfactorily succeeded. However, in practical planning stage of most engineering fields, there still lack scientifically adequate decision principle and process to be followed. Consequently, successful and unfavourable engineering projects still co-exist in our country and result in considerable losses. With the increasing development of national construction, if the wasteful situation can not be properly remedied, the long term economical loss and the delay of development progress will be beyond measures.

Furthermore, the topographic and geomorphical conditions of our mountain regions and desert lands are exceedingly complicated, the environmental condition is not desirable. The careless planning decision will be a factor to make the environmental destruction and disasters from bad to worse. The foreground is worrying.

In view of this situation, the research of qualitative and quantitative synthetic optimization from its preliminary conception, analysis of co-ordination of motive power and line standards, modeling, examination to the application in practical project, took more than 10 years, excluding the work of modeling of railway operating expenses in 60's.

Synthetic optimization has the nature of systems engineering, but is made much simplified and more flexible to adapt to practical works. The flexibility in methodology and the freedom from possible indiscriminate use of terms in any instance lead the author to adopt the present name, "synthetic optimization," for the research work and this text.

The economic effect of synthetic decision has been proved unexceptionally superior to the original designs of existing lines by traditional method and verified in the practical design of new trunk line project. Because, when strictly performed, it automatically eliminates the possible errors due to personal, bureaucratic, inexperienced and other prejudices and the economical losses resulting from the misco-ordination between related specializations and organizations.

Although the most examples of mathematic models are devoted to railway projects, the synthetic principle of optimization may equally be adopted by other civil engineering works. Because every engineering field involves: reforming of land, safety against disasters, environment protection, saving and regeneration of farmland, sand control and desert reclamation, co-operation among neighbouring engineering projects and the co-ordination of functional parts in the construction itself, the synthetic principle and method stated in this text may also be used internationally. Sincerely hope the widened use of them to economize the projects extensively.

The entire text is believed far from a perfect one. It is of the nature of primary idea and suggestions only with the confidence of usefulness and vitality. The synthetic principle and mathematical processes are subjected to supplement and perfection in the economic development and technical advancement which will undoubtedly be accomplished by the younger engineers and scholars.

The original text was a lecture manuscript given to the graduate students specialized in railway engineering from 1984 in South-West Jiaotong University. It may also be used as a reference material for the senior undergraduates with preferably the prerequisite courses of "Railway Design" and "Optimization Methods for Engineers". In recent years, through reduction of detailed materials and supplement of the subjects on engineering policy and professional ethic, the text has been made more adaptable as a reference for the designers and decision makers who are welcome to make comments and give opinions and suggestions.

## Grateful acknowledgements are offered to:

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— The calculations on railway operating expenses in early research work were made by the senior students in 1960 Shihjing Li, now Senior engineer of SW JT University, Senior engineer Zongming Liu of Shenyang Railway Administration jointly with Senior engineer Yongqi Sun of 3rd. Design Institute, MOR.

The optimization calculations on computer in 1985 were made by Associate Professor Shuhe Wu of SW JT University and Doctor Changqing Wang, now in Calgary University, Canada. Dr Wang also made partial financial aid to the publication of this edition.

The manuscript work was started in January, 1996, but regretfully, obstacles from misellaneous affairs delayed the publication for years.

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# CHAPTER 1

## SPLENDID ENGINEERING ACHIEVEMENTS AND DEFECTIVE WORKS IN CONTRAST

Among the civil engineering works in history, there were a world of differences between the successful and undesirable ones. The superior projects gave economic and social benefit to the people and offered everlasting advantage to mankind. While the inferior works brought about waste of manpower and materials and delayed the production development. And some projects might be disasters which could never be restored. The following examples may serve to explain the problem.

## 1.1 Typical Examples of World Famous Establishments and Things Undesirable

### 1.1.1 Dujiang Weir River Regulation and Irrigation Engineering

As one of the world earliest hydraulic engineering works, Dujiang Weir synthetic project, situated in the middle part of Sichuan Province, was designed and supervised by the famous local governor Li Bing and his son in 256-251 B. C.. The overflow weir and protection dikes are located in the middle reach of Min River, where the main course is successively divided into five large and small branches spreading over the West Sichuan plain. The engineering works including dividing points, overflow weir, regulating and protecting dikes, form an interrelated system. See the sketch of Dujiang Weir(Fig. 1. 1).

1. Min River
2. inner channel
3. outer channel
4. Town of Guanxain
5. dike protoection
6. over-flow weir
7. dividing point
8. Temple of Memory

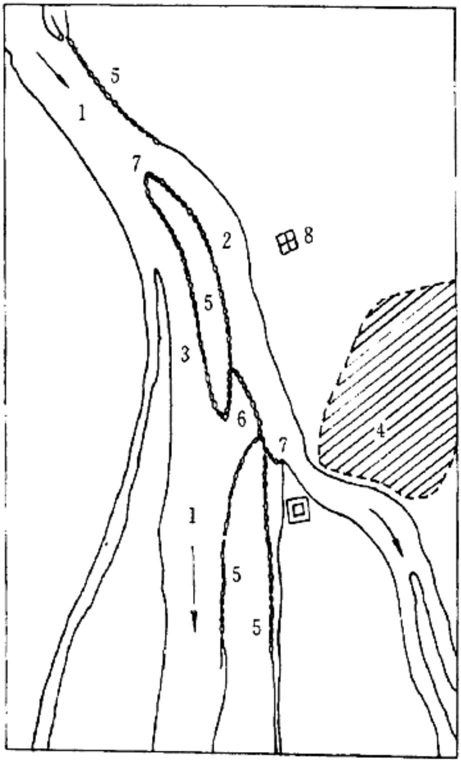


**Fig. 1. 1 Sketch of Dujiang Weir**

The overflow weir is made of local erodible materials (bamboo net and rock cobbles). The degree of erosion depends upon the amount of discharge. The weir, as the old tradition, is repaired once every year with limited reconstruction work. Thus, to a considerable extent, the flood automatically regulates itself to flow into the down stream channels and together with the dividing points, regulating and protecting structures, the quantities of flow is divided into desirable proportions among the branches.

In the following years, on the original basis, the local people continued to expand the effect of river regulation and the irrigated land. After 1950, water-power stations and sluice were built and gave more controlling power to the project. Up to recent years, the benefitted areas totalled 5 500 $km^2$. In these areas, flood does not happen and stable yields of farm products are ensured in spite of drought or excessive rain.

It is the ancient hydraulic project which brought on the long term economic development of the heartland of the biggest province. In China, the total area of mountain regions amounts to 66% of the entire territory and that of the farm lands is only around 11%. Under this circumstance, the Dujiang Weir project deserves to be an exceedingly valuable inheritance from our ancestors.

Now, let us discuss how and why in 2 250 years ago, when all the modern equipments, technical theories and building materials were not available, Li Bing and his son could achieve such excellent important work. It is impossible to trace the details of their investigation, design and construction of the great undertaking. But we are sure of two important points:

1. Lis definitely knew that they must master all the natural conditions of Min River and the entire basin. They must examine the variation and the reqularity of the river flow, meteorological phenomena of different years and seasons and the farmland requirements. In order to do these, they must have made exhaustive investigations with the primitive but clever and diligent methods for years after years.

2. It is impossible to obtain the best schemes of diversion of flow among the main and branch channels and for the height of wiers in a single design. They must have made numerous experiments and trial constructions until the famous maxims of maintenance method and the permanent water gauge were established for the coming generations.

These are just the spirit which we, the descendants, should keep in minds forever.

The people with discerning eyes of Sichuan built a magnificent temple as a memorial to the brilliant deed and the wide and everlasting social benifit. The education to the engineers of the world is still more significant. Now, all the technical instruments, books on design theories and construction, new materials and international experience are available. If any of our engineering projects is still inefficient, uneconomical or even disastrous, shall we not feel ashamed.

## 1.1.2 Sanmenxia Water Power Project

In comparison with Dujiang Weir and environment protection and hydraulic power engineering in Switzerland, Sanmenxia waterpower project on Huanghe River of North China may be called an engineering failure.

In the more than 5 000 km main course of Huanghe River, some 2 000 km pass through loess and sandy regions.

So that water of the middle and lower reaches constantly carry tremendous amount of sand silt throughout the year. In many stretches the silted river bed has been raised above the adjacent ground surface. Huge dikes have to be built and constantly increased in height and volume. The Huanghe River, in fact, is an extraordinarily big watertrough high above the towns and villages on both sides.

In 50′s, a large expensive dam with water-power station was constructed across the wide river of middle reach at Sanmenxia despite objections. The dammed reservoir, now, has been silted up seriously. Though undergone arduous effort of sand removing, only a small portion of the designed electricity output is left. The dam construction further speed up the silt precipitation in some part of the river. Now, the plan of the great undertaking of shelter forest are carried on. We hope the condition of land erosion may become better gradually. But the silted river bed will never be restored.

The main reason of the unfavourable decision, after all, was the negligence of reality of the local geological condition and silt content of the specific Huanghe River. The other reasons are out of the space of this text.

## 1.1.3 Forestry, Railways, Tunnelling and Water-power in Switzerland

Since early times, the Alpine people has had the tradition of protecting forests. The storm and melting water were largely detained and prevented from substantial erosion of the mountain slopes. From late 19th century, when water-power began to be utilized, further adequate regulation of rainfall was gradually accomplished. This gives the good foundation of farm, industry and regular downstream flow.

After the middle of 19th century, railways grew rapidly in this mountainous country of 43 000 $km^2$ and now, more than 6 million population. Various forms of railway were constructed, adhesion, rack and pinion, rack-adhesion and funicular railways, standard and narrow gauged, international and local. They constitute a three-dimensional railway system owned by the Federal Government and private enterprises. The maximum altitude attained by adhesion line is 2 257 m, rack &. pinion line, 3 454 m, rack-adhesion, 2 160 m and funicular line, 2 663 m. The maximum grade of standard gauged adhesion line is 27‰, for narrow gauged adhesion line, the limitation of grade is usually 60‰, but on an exceptional case the grade goes to 73‰. Thus, the Swiss railways, may be said, are able to reach anywhere in the great Alps.

The main features of Swiss mountain railways are: first, furnishing the required traffic service with least disturbance of the land forms; secondly, the railway increases its tractive power with the increasing demand of traffic amount by improving equipments rather than putting on heavy reconstruction work. Water-power establishment helped the industrial development as well as greatly empowered the railways. Now, practically all the lines are electrified. The traffic capacity of most lines has been many times as it was before the 2nd world war, while no much reconstruction work was added.

Another remarkable achievement which helped the railways in conquering mountains is the building of long tunnels. The 14.91 km Gotthard double track tunnel through the Alpine range was opened in 1882. Then, the 1st Simplon, 19.69 km long in 1906, 14.5 km L ötshberg double track in 1913 and the 2nd Simplon, 19.71 km long, in 1921 were completed. The decision of constructing such long standard gauged main line tunnels hundred years ago is worthy of praise. It saved long distance of line development on the mountains 3 000 m high.

All these engineering measures, in addition to the peaceful situation given by the long term international neutrality since before the 1st world war, made the small mountainous country the most prosperous and liveliest spot in the world.

Furthermore, owing to the control of storm water and river regulation in Alpine countries, all the European countries along the down stream rivers are greatly benefitted in flood prevention, navigation and water supply. These have brought on increasing industrial development in many countries for more than 150 years.

Contrary to the above two splendid examples, in the upper reaches of Amazon river of South America, Huang River of China, Brahmaputra River (the upper stretch is called Yaluzangbu River in Tibet, China) in India and Bengal where no much protection of environment and conservation of energy are adopted, or even the forests were distroyed in some places, the social and economical situations are far backward. People living along the rivers suffer frequent flood disasters and economic losses.

## 1.1.4 The Unfavourable Side of American Railroad Establishment

As for the enormous railroad in the United States, the implicated disasters upon the local people and the destruction to the environments brought on with the flourishing railroad development should not be neglected.

The American railroads are private enterprises independent to each other. Owing to the economical stimulation, the mining of various ore resources, including the "California gold rush" beginning in 1849, led to rapid development of railroad construction. Up to 1916, the total length of rail network exceeded 420 000 km. This was the favourable aspect of capitalist economical development. The early immigrants were chiefly landing on the east coast. It was mainly the railroad construction which brought the prosperity of the eastern regions to all over the country.

Shortly after the end of Civil War, in 1869, the first railroad to Pacific came into operation. It was just like the big Lanzhou-Xinjiang railway in China which for the first time reached the extreme west part in 1960's. The American rail network grew faster than the nation's enlargement and stabilization. In the year of 1916, the midst of first World War, the peak record of network was attained. In the period of 1840-1900, the country of U. S. was also puzzled by hostilities, such as, Spainish-American War and many battles against Mexico. It was marvellous that these conflicts did not have much influence on the railroad development. It showed evidently the inexhausible power of the private enterprises in promoting the economic establishment.

However, the huge American railroad network was not so perfect and healthy.

— The big and small railroad systems had different technical and operation standards of their own.

— Some of them were constructed with temporary structures, such as, timber trestle bridges, wooden culverts and station platforms. The construction of these railroads was just aiming at plundering mine materials but having no far-sight project.

— Later on, some roads were subjected to the competition of the highways.

As Arthur M. Wellington wrote in the Preface to the first edition of his book ***The Economic Theory of the Location of Railways*** in 1877, "…, all our railways are uneconomically located, …". Really, as imaginable, since 1916, many small rail lines were stopped to work with the mines shut down. Some were stopped under the competition of transportations. Others were abandoned with their decayed structures.

Gradually, many local railroads, through remoulding, were combined into trunk lines of 10 000, 20 000 km and even longer. But the total amount of railway network considerablly decreased. In the following decades, some 150 000 km railways were abolished.