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MACRO-ENGINEERING, HOW TO DECIDE?

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The time is long past for development of methods for evaluating macro-engineering projects, and/or systems programs and the adoption of some guidelines in decision-making, even though they may be rudimentary and will require considerable improvement.

Macro (meaning large or extensive), as applied to engineering, can describe size, technical difficulty, time required for design and construction, initial costs in money, size of labor force, time to completion, magnitude of impact, etc.

Macro-engineering (ME) is proposed too often as heroic enterprise and excluded from adequate evaluation, stating that conventional yardsticks and rules of management and budget control, do not apply. They are for the benefit of all mankind and that the benefits are needed regardless of most costs.

Some ME efforts become so apparent only when viewed after completion. New York City, London, Rome, etc., fall into this class; they "grew" without a prior prepared detailed blue print. Washington, D.C., Brasilia, Brazil, and the proposed new capital of Nigeria, are examples of progressively greater degrees of pre-planning.

"Hot" and "cold" wars involve ME. Such efforts are characterized as being based almost exclusively on the perceived comparative end-effectiveness of projects. Costs in dollars, environmental impact, etc., are relatively minor, if at all, considerations.

The Erie Canal, Panama Canal, Trans-Alaska Pipeline are examples of "unit" projects. They are discussed in Appendices A-D.

The National Highway Grid is an ME system. The federal government is considering the support of a coal slurry pipe distribution system. The comparison in costs and political/social/industrial aspects are quite interesting.

"Micro" decisions can result in "macro" situations. The "micro" decisions or efforts by one or two people may be consciously made because of the perceived and desired "macro" effects. The "Pill", incandescent electric light lamp, and the internal combustion engine are examples.

ME endeavors require significant effort or result in sizeable impacts on people, society, the economy, the environment, governments, and lifestyles.

The identification of impacts is difficult and classification into first-order, second and higher order groups, changes with time, political winds, inter-action of other ME, singular insignificant events, and discoveries that may occur after initiations of the ME.

The National Highway System was initiated so as to enable us to drive farther to obtain work or to play. The existence of the system results in the requirement to drive, and to drive farther, in order to work or play.

"Macro-engineering" can also be categorized by one of the following:

- a) It involves government funding, or other involvement, (guarantees, special tax incentives, etc.) because of the magnitudes of capital investment requirements the extent of environmental impact, the time span to completion.

- b) It requires exhaustible natural resources or ones that are renewable but only after a long gestation period.
- c) Large numbers of the population or particular segments of society will be effected.
- d) Requires participation by state governments and/or foreign governments.
- e) Obligates the government to monitor, control, and safeguard the products, plant, or residue for long periods of time or in the event of failure of the private sector to do so.

We have:

- a reached, or may have even overstepped, the limits of our economic, manpower, management, and social tolerance limits.
- b pre-occupation with government funding and risk assumption.
- c nurtured national and international pressure for spectacular technical advances, for political and or economic ends.

The demand for the earth's resources are almost beyond imagination. In the next 15 years we must mobilize as many raw materials as have been extracted during all of man's history on this planet. Within the next 10-15 years we must design, manufacture, install, and bring into full operation as much power production equipment as has been accumulated up to this point in our history.

A characteristic of technological advancement is a decreasing requirement for labor in production. Sophisticated, scientifically intricate production means increasing attention of scientists.

The unskilled are finding it virtually impossible to obtain work. They and their off-spring are locked onto a treadmill of poverty, early drop-out from school, dependence on welfare, and adoption of activities which are non-productive and encourage indolence. The profile of labor requirements of current ME shows no opportunities for spanning the gap between their position in society and the mainstream of an industrialized world.

Every LDC wants to make a quantum leap into modern industrialized nation status. The rising expectations of the masses of peoples of the Third World are encouraged and accelerated by television movies and newsprint. As a consequence, the standards of living in established countries of the First and Second Worlds are threatened by shortages in natural resources. Control of supply, which has been with the industrialized countries, is shifting to the Third World.

The commitment of capital to construct and tax support to operate, regulate, monitor, and dismantle strains the national economy. The social fabric, political security, physical and biological structure of our planet and its atmosphere are being affected in major ways.

There is a centralization of decision making by persons whose accountability in time is much shorter than the time to demonstration of failure or success. In many instances they will not be present to witness responsible or accountable for the original decision.

### Motivation

The motivations for initiating ME projects may be classed under personal desire for power, conceit, religion, monetary profit, political stability or advantage, national pride, competition, growth, health, safety, etc. (including "the good of mankind").

The most powerful motives are of a competitive sort:

"We want to come out on top."

We want to be able to credit ourselves with first place; to be second is bad, and to be second-rate is intolerable.

The competitive spirit and the desire to excel are important and an integral part of American life. There has always been an element emotional commitment to ME projects. If a project is seen as a challenge, the view is that it is good to excel, that it is good to test one's mettle against significant challenges.

Leaders and political parties seek to promote their political fortunes. The "ins" champion policies (goals, rules, and methods for achieving them) with an eye towards the next election. The "outs" look for weaknesses, failings, and omissions. They try to devise alternative policies with electoral appeal.

Political concern about ME is not primarily on the scientific and technological measures to implement the program but whether it will be a symbol for international cooperation or superiority or a vehicle for socio-political progress or advantage. [We should be curious about the values interests - the motives and stated reasons - that inspire domestic or international political behavior with respect to ME. To what extent

is a project motivated by a desire to enhance American prestige over the world or to have one's name recorded in the annals of history? To propose projects for "security," prestige and pride is "patriotic." To challenge ME purported to be for those ends is "unpatriotic".]

By enlisting private organizations in the performance of public functions, government involves them in politics and blurs the line between "public" and private industry. The private organizations retain advantage of private enterprise while serving the vital needs of the nation and still influencing their own futures. "Nationally" inspired ME may be for a private end.

The situation in which we find ourselves was expressed by T. Keith Glennan, first NASA Administrator:

"We need to have, and understand, nationally accepted goals or purposes.

"How can we decide how important it is to spend, on an urgent basis, the very large sums of money required to put a man into orbit, etc., unless we have a pretty firm grasp of what the purpose behind the whole space effort really is.

"And yet, who knows the answers to this and many similar questions today? Who is thinking about them and doing something about developing some answers?"

When a project is advocated how do we determine:

- a) that it will accomplish what its promoters claim
- b) what the hidden advantages and disadvantages are

- c) what common yardstick of "values" can be used to compare one project with others
- d) what the "true values" of each of the several classes of "costs" are
- e) how accurate the budget is? The Apollo project was estimated to cost about one billion dollars when submitted to Congress for approval. The actual cost was on the order of twenty-seven (27) billion dollars.

### Value

What is the value of a project? How do the values of one project compare with another? How can one compare different values? How can one apply a number to a value? What is a value "worth" in dollars?

Some values are only temporary or will exist only in the future. Some values exist only at the sacrifice of others.

- 1) Technology is becoming more voluminous and more complicated.
- 2) ME either have completion dates too far into the future to permit adequate assessment or no time table at all.
- 3) The complexity of much new technology and the time span to stages which permit reasonable evaluation so wide or indefinite that it is extremely difficult to anticipate how it will do its primary job and what its second-order consequences will be.

As our understanding of biological, ecological, economic, and social processes improves, as we observe and realize the immediate and future consequences of ME, we have an obligation, under our planet stewardship responsibilities, to evaluate to the best of our abilities our actions and to include their costs, monetary and otherwise, in our analysis and decision process.

Many of the major public engineering expenditures decisions have been characterized by "muddle through" by "rule of thumb" over the objections of "vested interests" and/or "wild-eyed idealists". Public money has been lavished often on "popular" projects with a very hazy idea of the return to be expected and even the extent and depths of all construction costs and obligations once completed.

Cost-benefit analysis may aid, but the present state-of-the-art cannot be applied to the problem of appraising the quality of a horse and rabbit stew. The rabbit being consequences, that can be measured and evaluated numerically, and the horse "the amalgam of external effects, (social, emotional, and psychological impacts and historical and aesthetic considerations) that be adjudged only roughly and subjectively. The horse is bound to dominate the flavor of the stew, meticulous evaluation of the rabbit cannot justify the ME.

There are inherent hazards in leaving of decisions about ME in the corridors of political power. The current establishment of economic and social priorities by Congress reflects, too much, political pressures by

vested interests. Can we create tools which the Congress and government officials might be obligated to employ as to maximize objective evaluation and action?

How does one determine the cost and benefit streams of government sponsored ME or supported?

### Risk

Investment by the private sector considers risk, the project will or will not "pay-back" as expected, "what are the odds?" With ME, where performance can only be measured many years after the start of the project and tens of millions, or in some cases, billions, of dollars have been invested, to what extent should government funded or supported reflect consideration of risk? Are the proposers subject to penalty if the pay-back is not as promised?

The government must improve its relationship with industry by increased emphasis on competitive award of contracts and cost-plus-incentive-fee contracts. It must increase pressure for industry to assume a greater share of risk.

## Conclusion

Improving the process by which ME is conceived, evaluated, approved, developed, financed, managed, and terminated is a challenging task.

With most ME, the attendant cost of hundreds of millions and billions of dollars, and the time scale from conception to realization, one wonders whether anything at all can be done.

The magnitude of the irreversible commitment to major projects which will steer policies and life styles for a few generations, our involvement in the internal affairs of other countries and the relationships between them and us, the hazard to the planet etc., makes it essential that we allocate a considerable portion of our attention and efforts to the task.

We must be concerned not only with efficiency (adherence to budgets and completion dates) but also to value (value related to all other economic and social needs and desires) and the objectives (sub-goals) as related to reaching long-term mission or direction for public policy.

The goals of public policy must be developed, specified, and ratified by the political process as an expression of the people's will.

There must be an awareness of, and comparison with, alternatives to a proposed project. Valid analysis requires fundamental research and experimentation on relationships between means and ends, results and costs.

ME has output or cost implications that extend significantly beyond the federal government's one-year operating and budgeting period, more often than not, beyond the tenure of political or personnel and

frequently into future generations. In the execution of ME responsibility for costs, and adherence to completion schedule cannot be completely assigned before hand.

Effective evaluation requires review of the standards of measurement, proper relative weighing of the several criteria all along the history of the ME. Not only should a comprehensive technology assessment precede the proposal, technology assessment must be conducted at frequent "milestones" during construction and throughout its use so that modification or termination is instituted at the proper time.

Socially responsible management of ME is virtually impossible. Too many facets of society are affected, some positively, some negatively.

More importantly, the Heisenberg uncertainty principle - the precept that the accurate measurement of an observable quantity necessarily produces uncertainties in one's knowledge of the values of other observables - applies in social behavior.

Evaluation requires the constant presence of awareness that the ME is always, some to a greater degree than others, self-serving. In our society we encourage competition and achievement by offering personal incentives (money, fame, power, etc.).

The scientist stands to get research funds, the university anticipates grants, the non-profit research organization wants contracts out of which it can pay high salaries, the trade union wants to keep up employment, the business concern wants profits, the trade-journal caters to the complex of readers, the congressman seeks re-election, the

promoter (governor, elected official, etc.) wants to bring more wealth to a state or region, and the U.S. President wants immortal fame - beginning within his tenure in office.

But these are "human" characteristics which account for our present state of industrial development, health care, medicine, etc. They cannot be eliminated, nor should we not try to completely stifle them.

We must learn to distinguish between:

- a) regulations which protect public's financial and other interests and
- b) regulations which result in a loss of industrial incentive, creative ability, and responsibility.

Overall there is a very definite limit to growth, and within that overall limit, a limit to rate of growth. World demand is not only for energy but also for food, forest products, minerals, fresh water marine protein, skilled labor, and so forth. It is a function of rising expectations, rising affluence, and rising population numbers. The technologies that underlie our economic system evolved in a situation of relative resource abundance. What we face is the task of imposing a rational and conscious of allocation.

There must be public identification as to who:

- a) needs
- b) wants
- c) advocates
- d) profits by
- e) loses as a result

The general public must be given a chance to hear open debate and an opportunity to register approval or disapproval.

It must be clearly understood, and why, who finances: and what are the risks during:

- a planning
- b construction
- c operation
- d dismantling (because of failure or outliving usefulness)

We must know if cancellation is possible and where along its life do the possibilities exist?

We must pay attention to relatively unsophisticated means to accomplish objectives. Means which are in small sizes, impact and dollar value. What can be done to accomplish the same results.

The New Testament of the Bible, is quoted, not to support a religious tenet, but to suggest that the subject of this paper is not new.

"For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether be sufficient to finish it?"

Luke 14:28

Appendix A

Trans-Planetary Subway Systems

Robert Salter of the Rand Corporation suggested, at the 1978 annual meeting of the AAAS, the adoption of the "Planetran" concept, a subway system moving at thousands of miles per hour, capable of crossing the United States in an hour or so. It was proposed as a possible alternative to the anticipated over-filled and hazardous airways/airports of the year 2078.

Who but the government could possibly begin to even explore the feasibility of such a project? Once commenced, who would be powerful and secure enough to stop funding if it seemed not to be viable solution to the problems? Once the feasibility study of this concept is begun, what chance would there be for any other project to replace it even if the alternative were more promising? How close to the actual costs can estimates be? What could the government do if it found that costs were exceeding estimates?

How do we compare it with other proposed solutions? Not only technical characteristics but human preferences, prejudices, and expected lifestyles which could change several times over the period required for project completion will have to be taken into account.

Appendix B

Erie Canal

The Erie Canal was the work of that remarkable generation in America which made the period between 1815 and 1860 an age of great national expansion. It was a bold scheme designed to bring the Mississippi through a northern waterway, on American soil, to the growing metropolis at the mouth of the Hudson River. The supporters of the idea stated that the result would be national growth, strength, and prosperity.

Travel between the west and the northeast coast cities was by poor roads, or in part, along the St. Lawrence River, which was closed by ice for a number of months and involved contact with Canadian government and terminated in Canadian cities.

It cost \$2.00 to send a barrel of flour 130 miles overland and that the same barrel could go by water from Albany to New York City for 25 cents, a distance of 160 miles. A waterway between Buffalo and Albany would provide cheap, safe, "American owned" transportation between the West and the East. A cannon worth \$400 in Washington cost \$2000 to transport to Lake Erie. At the Niagara frontier there was a foreign power, Canada, which controlled the only outlet of the Great Lakes to the ocean.

The commission charged with evaluating the "worth" reported favorably and included the statement, "After a lapse of two thousand years and the ravages of repeated revolutions...this national work shall remain...."

The report theme was: the potential productivity of the uninhabited Western lands, the pressing need for communication the visions of private and public gain, the fear of Canadian rivalry. The project was funded by New York State and administered by a board of Commissioners, all with political ambitions.

It was estimated that the canal could be completed in ten or fifteen years at a cost of six million dollars. The project, with its thousands of jobs, was tailor-made to augment the power of the patronage in New York. It cost a little over 7 million dollars, or about 16% more than estimated.

The canal did provide the promised communication with the West. Western products were exported through the canal to NYC in amounts greatly in excess of the original estimates. Merchandise reached the Midwest and the Northwest from the East coast through the canal. Emigrants traveled the routes by the thousands, and account for the rapid development of the West.

With the development of the railroad, the worth of the canal began to decline. It is non-existent today. It exceeded its predicted contribution to the development of the West. The economist, W.W. Rostow, cited it as the principal contributor to the "take-off" stage of national economic growth in the 1840's.

Was this ME effort a success?

Appendix C

Military Macro-Engineering

U.S. military ME efforts during both war and peace times have been described as cooperatives between the military, arms industry (and frequently political parties). It has often been argued that the military projects must be viewed with greater suspicion and concern.

The proponents are described as having well established vested interests and join in opposition to any form of disarmament plan, to promote new and more expensive projects and have seen to be engaged in an orchestrated "see-saw" escalation of an arms race with perceived enemy countries.

If there is any basis in fact for these charges? One wonders if it is at all possible to evaluate projects in an atmosphere devoid of profit motive, employment, and opportunities for the scientists and engineers, much less the eternal issues of personal pride, ambition, and egos of political and military leaders.

Appendix D

"Lessons Learned From Constructing The Trans-Alaska Oil Pipeline"

In 1968 a feasibility cost study a private group estimated that an oil pipeline system, from Prudhoe Bay to Valdez, Alaska, would cost \$1.046 billion for a 1.2 million-barrel-a-day capacity. On the basis of this estimate, decision makers calculated the cost of a barrel of oil delivered to the "lower 48" and concluded that the cost-benefit of project (including environmental impacts) were positive and that it would be in the best interests of the public to grant rights-of-way, through federal and state owned land, to a private company (Olyeska Pipeline Service Company) to design and construct the pipeline system.

Shortly after pipeline construction began in 1975, the company established a base control budget of about \$6.4 billion.

By Dec., 1977, at the completion of the line, the cost was \$7.9 billion.

It is argued that this project was privately financed. However, the federal and state governments on the basis of cost-benefit analysis using the original estimate granted rights-of-way from the Artic to the Pacific Ocean. And considered environmental damage worthwhile.

The General Accounting Office, at the request of the Senate Committee on Energy and Natural Resources, reviewed the project and recommended that the following should apply to similar future projects.

- a First and subsequent cost estimates should be viewed with skepticism.

- b As much site-specific data as is economically practicable should be obtained
- c Technical and geological uncertainties should be thoroughly investigated
- d Government approval should be contingent on detailed planning for management control, including budgetary controls
- e The Alaska Natural gas pipeline project's expenditures should have an ongoing Government audit to protect the public interest.

How much of the over-run could have been anticipated? Why was the cost estimate changed from 1 billion to 6.4 billion almost immediately after required government approval was obtained?

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