RAIL SECTOR POLICY ANALYSIS USING SYSTEM DYNAMIC APPROACH

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Abstract: The operation of Indonesia railway had been restructured three times. Now the railway is operated by a state owned enterprise called PT. Kereta Api (Persero) which mainly acts as train operator, although infrastructure maintenance is also delegated to PT. Kereta Api (Persero) on behalf of government.

The basic objective of the enterprise is to make profit from the train operation. Nevertheless this mission is hardly accomplished, as the budget arrangement for rail sector is uncertain. Nowadays national rail network had been significantly decreased; only minor capacity expansion took place in some corridor in Java, while services are generally in bad condition.

Using system dynamics approach, this paper reports the initial finding in developing a model for policy analysis in rail sector, Major sectors including transport market, financial, infrastructure, tariff, and government policy are modeled. Each sector will have the cause and effect, representing the real situation of the rail sector environment. The system evaluation is based on indicators such as quantity and quality of services as well as finance.

Based on the model, the performance of rail sectors under a certain policy setting is herein demonstrated.

Keywords: rail, policy, system dynamics, operational, financial

1. BACKGROUND

A small amount of public fund has so far been allocated to support the rail infrastructure operation and maintenance. Consequently, these adversely affect the service quality, train market share and thus income decrease. For long distance haul, competition with airlines is very fierce; train losses its share in this market segmentation. There is still no clear regulation and policy undertaken by government in resolving the situation. Comprehensive policy

analysis is required before policy formulation, so that the rail sector and its businesses can be undertaken in a healthy manner in achieving a more sustainable operation in the future.

The complexity of railway system management can be viewed as many factors and components involved in the interaction, these can be nonlinear in effect, dynamics, and counterintuitive in nature. The decision based on managerial intuition alone may prove to be countering productive. The relationships in these systems are seldom linear. In most cases, as it has a high degree of nonlinearity, it is rather difficult to analyze the problems using traditional management or quantitative approaches available in management science.

The dynamic behavior of such systems is governed by their structure, which is composed of various cause-effect relationships. There exist an information feedback, which drive these systems. Moreover, these systems are governed by endogenous relationships rather than external influences. The internal policies affect a great deal in shaping their performance.

Based on a system dynamics approach, this paper reports the initial finding in developing a model for policy analysis in the rail sector. Important sectors including transport market, financial, infrastructure, tariff, and government policy are modeled. The model can be used to assess a new policy environment introduced into the railway system.

2. RAILWAY MANAGEMENT: PROBLEMS AND SECTOR IDENTIFICATION

The first step in problem solving using the system dynamics approach is the identification and definition of the problem. A problem situation is the starting point for the whole modeling exercise. System dynamics is used to explain the causes of occurrence of a problem and suggest ways to overcome it. Following this approach, the identification of Indonesia railway problem is identified based on, amongst other:

- a. Formal perpetual review
- b. Group discussion/brainstorming
- c. Regular policy planning
- d. Policy review
- e. New policy formulation

These suggest that many sectors involve in the rail system management as shown in Table 1.

3. RAILWAY SYSTEM CONCEPTUALIZATION

The system conceptualization involves establishing model boundary, identifying causal relationship, and policy framework. In a system dynamics, all relevant factors are considered to have an influence on the system should be included. However, the model boundary depends upon the purpose of the study. System dynamics takes a very pragmatic view of the system-environment interaction including the details of the environment, particularly the way it reacts to the forces originating from within the system.

| Sector | Problem |
|----------------|--|
| Corporate | State owned enterprise |
| | Public company |
| | Restructuring and privatization |
| Government | Financing scheme (TAC, IMO & PSO) ¹ |
| | Tariff regulation |
| Finance | Bankrupt |
| | Financing |
| | Investment |
| | Capacity |
| Infrastructure | Depreciation |
| | Maintenance backlog |
| | Degradation of infrastructure quality |
| Operation | Commercial and non-commercial class |

Table 1. Sectors involved in Indonesia Railway System Management

A system is usually conceptualized in terms of components and interaction. In system dynamics framework, all the interactions are treated as cause-effect relationships. The system structure follows the policies, which are being conceptualized, through information feedbacks. A policy is a broad frame of reference or guideline in making a particular decision. A typical structure of a management decision indicates the feedback structure. A policy parameter must always lie within a feedback loop. The information feedback governs a physical decision variable, which changes the system state over time. The state of the system through feedback chains determines the value of decision variable. In this study, sectors relationship can be described based on the following mental map as shown in Figure 1.



Figure 1. Mental Map of Railway System Management

¹ PSO=public service obligation, compensation provided by the government, the basic price of which is defined by the difference between the production cost and non commercial tariffs specified by the government. IMO = infrastructure maintenance and operation cost, compensation for the cost of maintaining and operating the main infrastructure on behalf of the government. TAC= track access charge, cost charged to the company for the use of track owned by the government.

The mental map describes causalities and its relationship such as service, tariff relative, governmental policy and finance. Causality, which is indicated by positive sign, means that when the cause variable increases, effect variable would also increase. While causality which is indicated by negative sign, it means that the cause variable affecting the effect variable vice versa.

Finance is the important indicator in railway performance. Finance is influenced by services. If a company intends to improve services or add a new product, it needs cost and this will influence its financial performance. However, by increasing financial performance, the opportunity to improve services will be available. Moreover, services improvement will increase the amount of consumer. On the other hand, it will increase traffic load that influences the condition of facilities and infrastructure.

The common problem of Indonesia railway is the deterioration of commercial services. Fact, it does not cause the reduction of rail transport consumer. The mental map shows that there is other variable influencing positively the amount of transport consumer. The variable is potential consumer, which is potential to influence the rail services. Potential consumers tend to increase following the amount of resident or population.

Relative tariff represents the comparison of rail transport and competitor tariff, which will influences the amount of potential consumer. Recently the government regulates the non-commercial tariff, while commercial follow the market mechanism. This represents the regulations that give advantage to the consumer to choose the mode, which has the cheapest tariff.

In fact, the results of this regulation are that the air transport has more competitive tariff compared with rail transport and as a result, many consumers convert to air mode, especially for a long distance trip. Finally, it insists the company to conduct efficiency in all aspects. However many policies made by the company is subject to government regulation because PT. Kereta Api (Persero) is a state owned enterprise.

4. RAILWAY SYSTEM AND MODEL FORMULATION

The system conceptualization is to be translated into detailed model formulation involving the feedback loops, physical and information flows, variables and parameters. For model development, the data is taken from multiple sources and the system behavior is explained endogenously. Model is formulated in term of feedback loops. A feedback loop is created whenever an input to a system is affected by its output. The system dynamics modeling with causal feedback structures represents an endogenous effect of real system behavior, which is one of the sharp contrasts to the view often found from other approaches.

The system dynamics models for railway management move from the problem symptoms backward through causal chains to determine the problem root, which may be present elsewhere. This obviates the need for recognizing many exogenous variables. Ideally, a single exogenous variable is taken in the system dynamics model as a driving force.

Problems of Indonesia railway modeling are carried out comprehensively because it involves the corporate, government, finance, infrastructure, and production. Because this paper is not enable to present entirely models hence only model, which is based on infrastructure and government policy on financing scheme, is shown.

4.1 Railway Infrastructure Model

Figure 2 presents mental map that shows causality of variables involved in problems of railway infrastructure. The maintenance and traffic load influence the quality of rail infrastructure.



Figure 2. Mental Map as Representative of Infrastructure System Dynamics Model



Figure 3. Railway Infrastructure System Dynamics Model

Since the government owns the infrastructure of railway, hence the duty of maintenance and investment becomes the government's responsibility. Under the current management, the maintenance is delegated to the company. Nevertheless, because the government gives the

priority of fund usage for others sectors outside of railway sector fund for the maintenance and investment of rail infrastructure is often insufficient.

So the main problem is the lack of maintenance and investment funds, and on the other hand, the effort to improve financial condition by adding frequency of rail transport will increase traffic load imposed by rail and then rail becomes gradually deteriorate. Degradation of rail quality often effect incidences such as derailments, accident, etc. The fact that can be concluded is that when company desires to increase revenue by increasing frequency of rail transport, the service quality tends to deteriorate.

The equations of infrastructure model are described below.

| added_infra_quantity | = | liquidity_effect * required_investment | (1) |
|--|---|--|-------------------------|
| added_infra_quantity liquidity_effect | = | the infrastructure quantity which is added annually (kn the effect of finance performance on the in- investment | m/year) frastructure |
| required_investment | = | the required infrastructure investment (km/year) | |
| required_investment | = | MAX (0, depreciation+(required_infrastructure - INFRASTRUCTURE)/WPPR) | (2) |
| where : | | | |
| depreciation | = | the infrastructure quantity which is experience d (km/year) | lepreciation |
| required_infrastructure | = | total infrastructure quantity per year which is required railway operation (km/year) | l to support |
| INFRASTRUCTURE | = | the infrastructure quantity (km) | |
| WPPR | = | delay caused by time lag among providen fund and in construction (year) | frastructure |
| required_infrastructure where · | = | traffic_load / actual_capacity | (3) |
| traffic load | = | train traffic load on rail (ton/km-year) | |
| actual_capacity | = | actual capacity which is haven by infrastructure to su traffic load (ton/km-year) | upport train |
| depreciation where : | = | INFRASTRUCTURE / age | (4) |
| Age | = | actual infrastructure age which is effected by traffic le | oad (year) |
| Age | = | effect * normal_age * effect_traffic_load | (5) |
| Effect | = | effect on actual age which is caused by discrepancy among actual and required maintenance cost | |
| Normal age | = | normal infrastructure age (year) | |
| effect_traffic_load | = | effect traffic load on infrastructure age | |
| Effect | = | GRAPHCURVE(MC/MCR,0,0.25, | |
| MC | _ | [0,0.38,0.55,0.7,0.82,0.89,0.97]"Min:0;Max:1.5"]) . | (6) |
| IVIC | _ | (UKAFH(1)) (11) $($ | |
| | | [0.2, 0.22, 0.23, 0.23, 0.24, 0.2, 0.24, 0.20, 0.20, 0.19, 0.27, 0.27, 0.28, 0.20, 0.33"Min(0:Max-1"])) * MCP | (7) |
| | | 0.27, 0.20, 0.27, 0.35 with 0.101 at 1.1 | (1) |

| MCR where : | = | INFRASTRUCTURE * MC_per_UI (8) |
|-------------------------|---|--|
| MC | = | infrastructure maintenance cost (Rp/year) |
| MCR | = | requirement of maintenance cost (Rp/year) |
| MC_per_UI | = | infrastructure maintenance cost per unit of rail length (Rp/km-year) |
| MC_per_UI where : | = | actual_capacity/ normal_capacity * MC_per_UI_annual (9) |
| Normal_capacity | = | normal capacity which is haven by infrastructure to support train traffic load (ton/km-year) |
| actual_capacity where : | = | normal_capacity * press_TL (10) |
| press_TL | = | effect to increase traffic load on rail above its normal |
| press_TL | = | GRAPH(traffic_load/potential_TL,0,10, [0,7"Min:0;Max:10"]) (11) |
| where : | | |
| potential_TL | = | normal traffic load which can be imposed on rail (ton/km-year) |

4.2 The Financing Scheme Model

Figure 4 represents mental map that shows the influence of government policy on railways financing scheme to company financial condition. For improvement of railway performance, the policy reform and restructuring of Indonesia railway sector had been started since 1995. This program is in line with the program of Railway Efficiency supported by the World Bank. One of the programs is to execute the restructuring of railway financing through a budget arrangement between government and the company, the so-called PSO, IMO and TAC.



Figure 4. Mental Map as Representative of Financing Scheme Policy System Dynamics Model



Figure 5. Financing Scheme Policy System Dynamics Model

The equations and relationships in the financing scheme are explained below.

| Net | = | received_IMO + received_PSO - TAC | | (12) |
|------------------------|------|---|--------------|--------------|
| Where : | | | | |
| Received_IMO | = | IMO fund which is received by company | (Rp/year) | |
| Received_PSO | = | PSO fund which is received by company | (Rp/year) | |
| TAC | = | track access charge (Rp/year) | | |
| TAC Where i | = | (dc + received_IMO) * f | | (13) |
| Dc | = | infrastructure depreciation cost (Rn/year) | | |
| f | = | corrective factor value | | |
| 1 | | concentre lactor value | | |
| Dc | = | depreciation * upi | | (14) |
| Where : | | | | |
| depreciation | = | the infrastructure quantity which ex (km/year) | periences de | epreciation |
| Upi | = | infrastructure price unit (Rp/km) | | |
| Received IMO | = | IMO from GOV | | (15) |
| IMO from GOV | = | desired IMO * correction for IMO from | n GOV | (15) |
| Desired IMO | _ | MCD + other IMO | II_00 v | (10) |
| Desired_IMO | _ | MCR + Ouler_IMO | | (17) |
| where : | | | | |
| correction_for_IMO_fro | om_(| GOV = corrective factor which depen for IMO fund | ds on goven | ment ability |
| MCR | | = requirement of maintenance co | st (Rp/year) | |
| other_IMO | | = other cost which is included wi | thin IMO fun | d (Rp/year) |

| Received_PSO | = | PSO_from_GOV | | (18) |
|------------------------|------|--|--|--------------|
| PSO_from_GOV | = | desired_PSO * correction | n_for_PSO_from_GOV | (19) |
| desired_PSO | = | marginal_rev_cost_EKO |) | (20) |
| Where : | | | | |
| correction_for_PSO_fro | om_(| OV = corrective factor for PSO fund | or which depends on govenn | nent ability |
| marginal_rev_cost_EK(| C | = cost which is o economic class | btained from cost reduced by s (Rp/year) | revenue in |

The public service obligation (PSO) is a compensation provided by the government, the amount of which is defined by the difference between the production cost and non commercial (economic class) tariffs specified by the government. The second, infrastructure maintenance and operation (IMO) is government's responsibility to provide the budget for infrastructure maintenance so that infrastructure can be safely passed and used according to technical specification and economic age. Track access charge (TAC) is an obligation which must be provided by train operator that uses the infrastructure owned by government.

The financing problem emerges when the budget arrangement under PSO, IMO and TAC is not fully implemented. In 2002 government only paid Rp 60 billion out of Rp 463 billion agreed upon and Rp 106 billion in 2003. Until now there has been accumulated to Rp 1.07 trillions deficit². The maintenance of infrastructure (IMO) fund is not directly spent by government to improve railway infrastructure but it was delegated to PT. Kereta Api (Persero) to carry out the maintenance jobs. From the company perspective, IMO fund is perceived as income in the company cash flow. As a result, the allocated fund for infrastructure maintenance is further subject to company policy whether or to be allocated for maintenance.

Lack of fund for infrastructure maintenance and operation directly affects to the quality of services. Requirement of infrastructure maintenance cost is also directly influenced by the railway safety goals. Frequently, accident caused by existence of damage or trouble of signal system, rail fatigue, landslide, train telecommunications, trouble caused by erosion, etc.

The company has responsibility to conduct public services, as it was state-owned company. Practically the company perceived that PSO fund is less than expected; this causes a loss in company cash flow. On the other hand, government perceived that the unit of production cost proposed by the company is invalid.

Track access charge (TAC) is equal to a proportional factor multiplied by the sum of IMO and infrastructure depreciation. The proportional factor is basically determined by government policy, mainly the availability of public spending, although originally it was intended to balance public policy towards road and rail. Higher factor will subsequently influence the company financial condition.

Requirement of operating expenses, such as lack of incentive to PT. Kereta Api (Persero) will influence the level of service and safety. For example train doorman, signal and station, and also frequent inspection of rail condition are also crucial to influence the safety of rail transport. Ideally, the PSO, IMO, and TAC scheme should be accountable, and there should be a clear roles and authority amongst the government as the infrastructure owner and PT. Kereta Api (Persero) as train operator, as well as infrastructure provider.

 $^{^{2}}$ 1 US \$ = Rp 9400

5. SIMULATION AND VALIDATION

The dynamic behavior generated by simulating the system dynamics should exhibit the symptoms that lead to an understanding of actual behavior of the system under study. The model is subject to external shocks and random fluctuation. Normally, the model is simulated under extreme conditions and some behavior management decision can also be examined.

Validation of system dynamics models is basically a process of enhancing confidence in the model, although it is not dealing with its absolute validity. The validation tests are predominantly qualitative, in sharp contrast to other quantitative models which are validated quantitatively. In fact the validation process is inherent with the process of model development. The validation is aimed at improving the structure, behavior, and rationale policy implications.

The results of Indonesia railway model simulation and validation are shown at Figure 6. In general it can be said that the model development can mimic the historical data to some extent. The discrepancy that occurs in year 1999 is due to an eventual policy that had been introduced in that period.



Figure 6. Comparison between Model Output and Historical Data

6. POLICY ANALYSIS AND IMPROVEMENT

The ultimate purpose of whole modeling is to improve policies design so as to improve the system behavior. The policy design is based on the understanding the real system behavior.

6.1 Policy Analysis

Unlike some other modeling methodologies such as operation research, which may directly attempt to devise a policy design, system dynamics makes it imperative to have a basic understanding of the underlying causal structure before getting into the realm of policy design. Further analysis can generate insights into the policy structures and their impacts in the real system so as to identify the leverage points for designing new policies.



Figure 7. Flow Diagram of Railway Problem

Attempt to understand the structure of railway sector policy is depicted in Figure 7. Having developed the railway model, the model should be validated and tested prior to implementation. This step can be referred to the behavior analysis. Behavior analysis will lead us to identify the root of the problem. This can be implemented by changing value of every variables and examining simulation output. Then the result is compared among, and the most influential variable can be identified. This variable is referred as the root of the problem. Policy is aiming on how such variable or problems can be eliminated or controlled, such that those factors no longer contribute most to problems.

The lack of maintenance fund accumulates as a maintenance backlog. As can be shown in Figure 7, the maintenance backlog continually increases every year and this will cause the deterioration of service quality. The degradation of service quality certainly causes the attractiveness of rail transport. This in turn decreases rail market share.

6.2 Policy Improvement

Based on the understanding of the above system, new policies are designed intuitively to obtain a desired behavior. As the social systems are counterintuitive in nature, new policy design directly might not give the desired results and trial and error based structural changes are to be implemented, though with increasing understanding it becomes more intelligent.

New policies are designed to obtain behavior in uncertain future. It is assumed that the causal structure generating past behavior will continue to remain valid in future also, but the parameter values might change drastically. Certain unexpected events can make some causal mechanisms inoperative or may create new causal mechanisms. Due to that condition, the policies are tested for their robustness with parametric and structural changes. However, if the human value system totally changes in future demanding a new performance in the model objectives the system dynamics model becomes useless for the future and should be recreated.

In Indonesia railway problem, the policy is developed based on the ability to overcome the problems of Indonesia railway. The continual deterioration of service quality highlighted various problems which emerge in railway system. This problem is started from lack of fund provided by government and corporate culture management that put priority in other sectors in the expense of infrastructure maintenance.

Financing scheme improvement

Normally, public fund is given to company in the form of net {(IMO + PSO)-TAC}. Problem emerges when the allocated fund given to the company less than required, hence fund which ought to be used for maintenance of railway infrastructure is redistributed to other sectors. Policy design is developed for improvement of IMO, PSO and TAC scheme.



Figure 8. Mental Map Represent Financing Scheme Policy Improvement Model

Debt Policy model

This policy governs how a company raises external financing through short long term debt. Short term borrowing responds to discrepancies between company's desire and actual cash flow. Short term borrowing is used to correct temporary or short term, discrepancies. And long term financing respond to differences between investment and cash flow from operations. A company uses long term financing to invest in capital equipment. Positive cash flow from operations reduces the amount of long term financing needed for such investment. Short term debt policy model is described in this paper as shown in Figure 9.



Figure 9. Short Term Debt Policy Model

Equation 20 defines short term borrowing. Short term borrowing, STB, equals to indicated change in cash ,ICC, multiplied by effect of current ratio on short term borrowing, ECRSTB. As described next, ECRSTB places financial constraint on borrowing.

| STB | = | IF (TIME < year_policy_II , government_debt + tax_debt + others_ ECRSTB*ICC) | _debt, (20) |
|--------|---|---|----------------|
| Where: | | | |
| STB | = | Short term borrowing | |
| ICC | = | Indicated change in cash | |

ECRSTB = Effect on current ratio on short term borrowing

ICC is defined as the difference between desired cash ,DCASH, and cash ,CASH, divided by time to adjust cash ,TACASH, DCASH reflects a transaction demand for cash.

| ICC | = | (desired_cash - CASH)/TACASH | (21) |
|--------|---|------------------------------|------|
| Where: | | | |
| ICC | = | Indicated change in cash | |
| DCASH | = | Desired cash | |
| TACASH | = | Time to adjust cash | |

Effect of current ratio on short term borrowing, ECRSTB, represents the constraint placed on the company by financial institution. A current ratio near zero implies a current liability is greater than current assets, so that short term financing arrangement is very unlikely.

| ECRSTB | = | GRAPHCURVE(current_ratio,0,1,[0,0.3,0.82,1"Min:0;Max:1"]) | (22) |
|--------|---|---|------|
| Where: | | | |
| ECRSTB | = | Effect of current ratio on short term borrowing | |
| CR | = | Current ratio | |

Equation 23 states that short term payments, STP, equals indicated short term payments, ISTP, multiplied by effect of short term debt on payments, ESTDP. As given by equation 5, indicated short term payments are positive when indicated change in cash negative (cash greater than desired cash)

| (GRAPH(TIME,1991,1,[0,0,19.446,8.138,0,1.938,0,0,1.742"Min:0;Ma , ESTDP * ISTP) | (23) |
|---|------|
| Where: | |
| STP = Short term payments | |
| ISTP = Indicated short term payments | |
| ESTDP = Effect of short term debt on payment | |
| ISTP = $-1 * MIN(0,ICC)$ | (24) |
| Where: | |
| ISTP = Indicated short term payments | |
| ICC = Indicated change in cash | |

ESTDP represents the difficulty of repaying short term debt as it falls. The independent variable is short term debt, STD, divided by ISTP. The independent variable measures the number of days of short term debt outstanding at the indicated short term payments rate. Division by ISTP essentially gives a scaling to the level of short term debts. At low levels of short term debt repayment of loans becomes increasingly difficult until, for a value of zero short term debt, no debt payments can be made.

| ESTDP | = | GRAPHCURVE(SHORT_TERM_DEBT/(MAX(0.001,ISTP)), | |
|---------|---|---|-----|
| | | 0,1,[0,0.5,0.76,0.9,1"Min:0;Max:1"]) | (6) |
| where : | | | |
| ESTDP | = | Effect of short term debt on payments | |
| ISTP | = | Indicated short term payments | |

6.3 Result of policy improvement

Common problem in Indonesia railway is the lack of finance that causes deterioration of infrastructure quality. This influences the quality of service; as a result the amounts of consumers gradually decrease. Finally, that condition will influence company's revenue and cause accumulation of finance problem which is identified as a causal loop problem.

System dynamics approach is able to analyze this problem which has been described in this paper. The result of policy improvement on budget arrangement as well as Business as Usual (BAU) condition is depicted in Figure 10, showing level of the infrastructure quality indices.



Figure 10. The Output under Two Policies Setting

Deterioration of infrastructure quality caused by financial problem is highlighted as one of the underlying problems. Financial policy such as a sufficient budget arrangement between government and the company as well as the provision of external financing through short and long term debt can gradually improve infrastructure condition.

7. CONCLUDING REMARKS

The railway problems analysis in this paper particularly study the causality in internal system causes the deterioration of finance performance. The result show that policies taken by government as infrastructure owner and PT. Kereta Api (Persero) as train operator imply the emerged problem.

A prototype of railway system management model based on a system dynamics has been developed and demonstrated. In the future development of the model, it is intended to enhance the capability of the model, among others, in emulating the option and effect of company restructuring effort in the railway management undertaking as well as the influence of local government involvement in the provision of the railway services.

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