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Integration of DEA and AHP with computer simulation for railway system improvement and optimization ☆

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Abstract

This paper presents an integrated simulation, multivariate analysis and multiple decision analysis for railway system improvement and optimization. Furthermore, the integrated model is based on data envelopment analysis (DEA) and analytical hierarchy process (AHP) that is integrated with computer simulation [24]. The integrated DEA and AHP simulation model can be used for selecting optimum alternatives by considering multiple quantitative and qualitative inputs and outputs. First, computer simulation is used to model verify and validate the system being studied. Second, AHP methodology determines the weight of any qualitative criteria (input or outputs). Finally, the DEA model is used to solve the multi-objective model to identify the best alternative(s) and also to identify the mechanism to optimize current system. An 800-km train route system was selected as the case of this study. Visual SLAM language was used to develop the simulation model of the railway system. The objective of simulation model is to increase reliability related to the time table of the passenger trains, to decrease average traverse time of passenger trains and to decrease average traverse time of cargo trains. In addition, for multivariate assessment of the alternatives by DEA, safety and cost factors are derived and considered from an AHP analysis. Previous studies use simulation and DEA based on quantitative variables for identification of the most efficient scenarios, while this study considers both quantitative and qualitative variables for efficiency assessment and performance optimization by integration of simulation, DEA and AHP. This is quite important for systems where some of their performance measures are qualitative such as railway and production systems.

Keywords: DEA; AHP; Simulation; Integration; Efficiency; Optimization; Railway system

☆ This paper presents a unique integrated computer simulation, AHP and DEA approach for railway system improvement and optimization. Previous studies use simulation and DEA based on quantitative variables for identification of the most efficient scenarios, while this study considers both quantitative and qualitative variables for efficiency assessment and performance optimization by integration of simulation, DEA and AHP. This is quite important for systems where some of their performance measures are qualitative such as railway and production systems.

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1. Introduction

Computer simulation has been known as an effective tool in solving real problems. After constructing model of the system, in order to solve many cases with this method, decision-makers review the various scenarios with created model to select the optimum scenario. In some cases, there are some criteria which can not be obtained simply by using simulation [24]. The paper propose the integrated model by obtaining quantitative data from simulation, qualitative data from AHP technique and utilizing DEA to solve this multi-objective problem.

AHP was designed to solve complex multiple criteria problems. It allows decision-makers to specify their preferences using a verbal scale [26]. This verbal scale can be very useful in helping a group or an individual to make a fuzzy decision. DEA is a methodology based on a linear programming (LP) model for evaluating relative efficiencies of decision making units (DMUs) with common inputs and outputs. It is used for ranking and analysis of DMUs such as industries, universities, hospitals, cities, facilities layouts, etc [34,3,5,6]. Sinuany-Stern et al. [31] extended the DEA analysis beyond the mere classification of efficient/inefficient to a full ranking, by incorporating AHP. Shang and Sueyoshi [30] used an accounting procedure to determine the DMU inputs. They used an AHP model to examine non-monetary criteria associated with corporate goals and long-term objectives, and simulation model was then used to analyze the tangible benefits. Azadeh et al. [4] introduced a framework for re-design of manufacturing systems into practical optimum just-in-time systems by integration of computer simulation and analysis of variance. Ertay and Ruan [12] illustrate a decision making approach based on DEA for determining the most efficient number of operators and the efficient measurement of labor assignment in cellular manufacturing system. The objective is to determine the labor assignment in CMS environment. Yang and Kuo [33] and Ertay and Ruan [13] used DEA and AHP to solve layout design problem.

Scheduling of the movement of trains is one of the most complex non-linear programming problems, for which various models have been developed and presented so far. For most situations, a closed form expression does not exist due to versatility and complexity of the imposed operations and constraints. Simulation has been used in various area of research [16,11]. Simulation modeling approach is the only ideal tool for solving complicated priorities of cargo and passenger train scheduling. In fact, due to the complexity of such problems, most of the previous research has been performed by utilizing computer simulation methodologies. The advantage of computer simulation methodologies is that they provide feasible solutions within a short period and they can be used to prepare, correct and modify periodical timetable for movement of trains. Nedeljkavic [21] used a heuristic method to generate the main program for movement of the trains based on human-computer interaction in the western Australian railway system. Their approach could be used automatically or manually for both single and double tracks. Allen, Mabrauk and Weigel [1] developed expert system and simulation model for problem with meeting points of trains. Scarldua and Silvade [29] utilized expert knowledge given there are different goals for meeting points and by passing train problems. Taylor and Peterson [23] presented a deterministic simulation model to evaluate the effects of train distribution on performance and capacity of tracks. Their model was developed for the mixed networks of single and double tracks to minimize costs with fixed speed of trains. Jovanovic and Haker [17,18] presented a model for detailed description of train scheduling. Their approach was developed by integration of a prototype model based on Monte Carlo simulation technique, a graphical interface for the user and a database system. Jovanovic et al. [18] employed branch and bound method for solving mix integer linear programming model to achieve maximum reliability. Also, Carey et al. [10] presented a heuristic method for the same objective. Carey et al. [9] and Kraay et al. [19,20] proposed a heuristic method to minimize deviation from scheduled plans and a mixed integer programming for minimizing the fuel consumption and delays. Braanlund et al. [8] and Nou [22] used Lagrangian relaxation with the same objective. With the aim of minimum delays and operational costs Higgins [14] presented mix integer linear programming and solved it by branch and bound method. Higgins et al. [15] used heuristic decomposition to minimize risk delays. In addition, their approach has three algorithms for optimization and prioritizing trains meeting points. Taherpoor [32] used a previous model to solve and analyze the problems of cargo trains scheduling based on simulation method. Azadeh et al. [7] assumed that trains have variable speed capabilities and passenger trains have fixed schedules. Then, the cargo trains were created randomly in the simulation model to identify optimum movement combination of trains such that total delays in railroad network are minimized.

2. The integrated DEA and AHP simulation model

The integrated DEA and AHP simulation model is shown in Fig. 1. The modeling and simulation process focuses on formulating and solving a real system such as train scheduling problems. Furthermore, the system being studied is simulated, verified and validated. The next step involves scenarios definition. Data related to problem objectives would be extracted from simulation with respect to selected scenarios. Next, AHP is used to quantify qualitative data. The purpose of AHP is to provide a vector of weights expressing the relative importance of alternatives for each criterion. AHP requires four steps: (1) structuring the hierarchy of criteria and alternatives for evaluation, (2) assessing the decision-makers evaluations by pair-wise comparisons, (3) using the eigenvector method to yield priorities for criteria and for alternatives by criteria and (4) synthesizing priorities of the alternatives by criteria into composite measures to arrive at a set of ratings for the alternatives. The decision maker must express his/her preference between each pair of elements. Each pair-wise comparison is scored as: equally important (1), weakly more important (3), strongly more important (5), very strongly more important (7), and absolutely more important (9) [26]. The final step utilizes DEA for ranking and analysis of scenarios.

The two basic DEA models are CCR and BCC with constant returns to scale and variable returns to scale, respectively. DMU_0 is assigned the highest possible efficiency score ($\theta_0 \leqslant 1$) that constraints allow from the available data by choosing the optimal weights for the outputs and inputs. If DMU o receives the maximal value $\theta_0 = 1$, then it is efficient, but if $\theta_0 < 1$, it is inefficient, since with its optimal weights, another DMU receives the maximal efficiency. Basically, the model divides the DMUs into two groups, efficient ($\theta_0 = 1$) and inefficient ($\theta_0 < 1$) , by identifying the efficient of the data. The original DEA model is not capable of ranking efficient units and therefore it is modified to rank efficient units [2].

The original fractional CCR model (1) evaluates the relative efficiencies of n scenarios or DMUs ($j = 1, \ldots, n$), each with m inputs and s outputs denoted by $x_{1j}, x_{2j}, \ldots, x_{mj}$ and $y_{1j}, y_{2j}, \ldots, y_{sj}$, respectively, by maximizing the ratio of weighted sum of outputs to the weighted sum of inputs. Moreover, after verification and validation of computer simulation, n scenarios or DMUs with $m + s$ quantitative and qualitative characteristics (inputs or outputs) are defined. Quantitative inputs and outputs are directly inputted to DEA from simulation results, whereas qualitative inputs and outputs are first handled by AHP to be averted

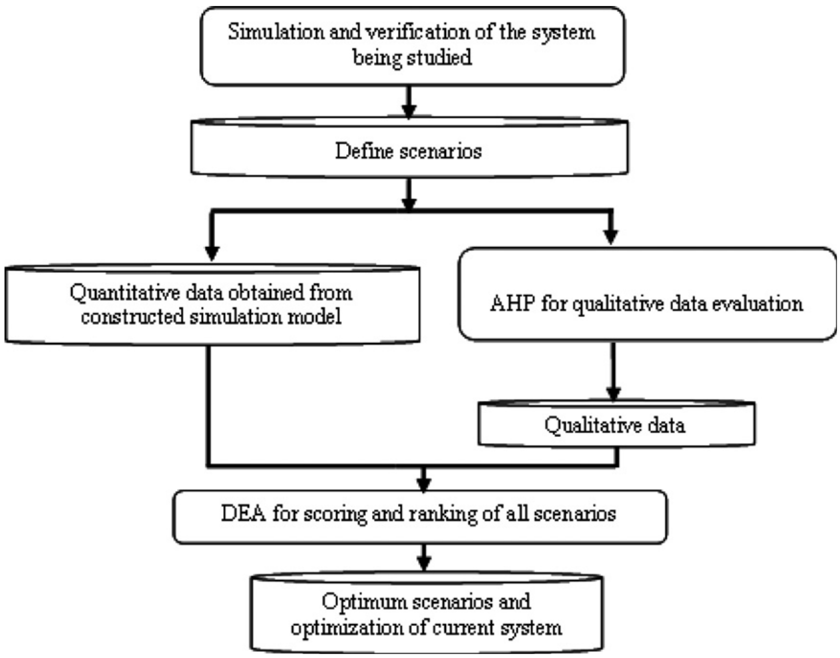

Fig. 1. Integrated DEA AHP Simulation Model.

to quantitative inputs and outputs for DEA model. Furthermore, computer simulation and AHP programs generate quantitative and qualitative inputs and outputs to be used in DEA, respectively.

$$
\begin{aligned}
&\text{Max} \quad \theta_{j0} = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \\
&\text{s.t.} \\
&\quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leqslant 1, \quad j = 1, \ldots, n, \\
&\quad u_r, v_i \geqslant 0,
\end{aligned} \tag{1}
$$

where y_{rj} is output generated by simulation and AHP for $r = 1, \ldots, k, k+1, \ldots, s$, respectively. And x_{ij} is input generated by simulation and AHP for $i = 1, \ldots, g, g+1, \ldots, m$, respectively In model (1), the efficiency of DMU_o is θ_o and u_r and v_i are the factor weights. However, for computational convenience the fractional programming model (1) is re-expressed in linear program (LP) form as follows:

$$
\begin{aligned}
&\text{Max} \quad \theta_0 = \sum_{r=1}^{s} u_r y_{r0} \\
&\text{s.t.} \\
&\quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leqslant 0, \quad j = 1, \ldots, n, \\
&\quad \sum_{i=1}^{m} v_i x_{i0} = 1, \\
&\quad u_r, v_i \geqslant \varepsilon, r = 1, \ldots k, k+1, \ldots, s i = 1, \ldots, g, g+1, \ldots, m,
\end{aligned} \tag{2}
$$

where ε is a non-Archimedean infinitesimal introduced to ensure that all the factor weights will have positive values in the solution. However, the LP model (2) does not allow for ranking of efficient units as it assigns a common index of one to all the efficient DMUs in the data set. Therefore, the dual of model (2) is modified by [2] for DEA based ranking purposes, as follows:

$$
\begin{aligned}
&\text{Min} \quad \theta_0 - \varepsilon \left[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right] \\
&\text{s.t.} \\
&\quad \theta_0 x_{i0} = \sum_{j=1, j \neq 0}^{n} \lambda_j x_{ij} + s_i^-, \quad i = 1, \ldots, g, g+1, \ldots, m, \\
&\quad y_{r0} = \sum_{j=1, j \neq 0}^{n} \lambda_j y_{rj} - s_r^+, \quad r = 1, \ldots, k, k+1, \ldots, s, \\
&\quad \lambda_j, s_r^+, s_i^- \geqslant 0, \quad \text{for all } j, \; j \neq 0.
\end{aligned} \tag{3}
$$

Model (3), which excludes DMU_0, is under evaluation from the input–output constraints, so that the efficient units are assigned an index of greater than one and the index for inefficient units is identical with that of model (2). An insufficient number of DMUs for a DEA model would tend to rate all DMUs 100% efficient, because of an inadequate number of degrees of freedom. A proper DMU number is required for identifying a true performance frontier. A rule of thumb for maintaining an adequate number of degrees of freedom when using DEA is to obtain at least two DMUs for each input or output measure. Also, it would identify means to optimize current system. As mentioned, there are n scenarios or DMUs with $m + s$ quantitative and qualitative inputs or outputs. Quantitative inputs and outputs are directly inputted to DEA from simulation results, whereas qualitative inputs and outputs are first handled by AHP to be averted to quantitative inputs and outputs for DEA model. Furthermore, computer simulation and AHP programs generate quantitative and qualitative inputs and outputs to be used in DEA, respectively. Thus, model 4 is developed as follows:

$$\text{Min} \quad \theta_0 - \varepsilon\left[\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right]$$

s.t.

$$\begin{aligned}
&\theta_0 x_{i0} = \sum_{j=1, j\neq 0}^{n} \lambda_j x_{ij} + s_i^-, \quad 1 \leqslant i \leqslant g,\\
&y_{r0} = \sum_{j=1, j\neq 0}^{n} \lambda_j y_{rj} - s_r^+, \quad 1 \leqslant r \leqslant k,\\
&\theta_0 w x_{i0} = \sum_{j=1, j\neq 0}^{n} \lambda_j w x_{ij} + s_i^-, \quad g < i \leqslant m,\\
&w y_{r0} = \sum_{j=1, j\neq 0}^{n} \lambda_j w y_{rj} - s_r^+, \quad k < r \leqslant s,\\
&\lambda_j, s_r^+, s_i^- \geqslant 0, \quad \forall j,\ j \neq 0,
\end{aligned} \tag{4}$$

where wx_{ij} and wy_{rj} are weights of qualitative inputs and outputs calculated by AHP method. Also, x_{ij} and y_{rj} are quantitative inputs and outputs calculated by computer simulation.

The proposed model is applied to scheduling of cargo and passenger trains problem discussed in the next section. The objectives of this problem are: (1) to increase the reliability of time table passenger trains, (2) to decrease the travel time of the cargo trains and (3) to increase the safety of travel and (4) to decrease the costs.

3. Empirical illustration

The integrated model is applied to scheduling of cargo and passenger trains traveling on a major track covering with fifty stations. The passenger trains have priority over cargo trains and are prescheduled. This is not the case with cargo trains and there is a need to develop a scheduling plan for the cargo trains. Hence, the railroad system is not operated effectively to transport the maximal amount of goods. Fig. 2 presents the overview of the system and Fig. 3 shows the limitations associated with stations and blocks. A train (cargo or passenger) is permitted to travel from station j to station k if the block between j and k is empty and maximum

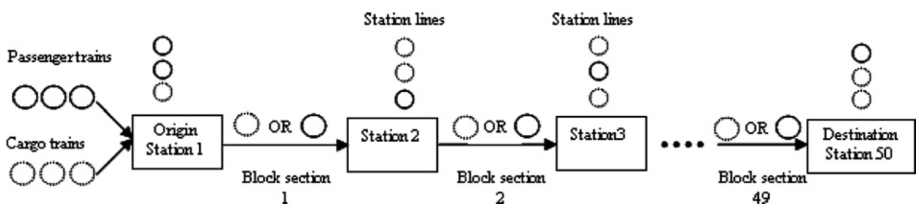

Fig. 2. Overview of the cargo and passenger trains.

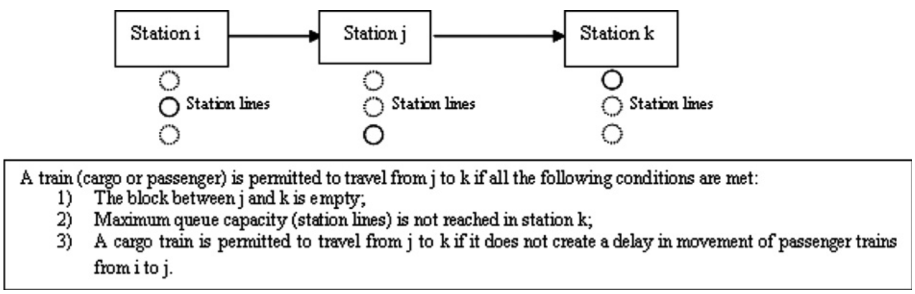

Fig. 3. Schematic diagram of the model limitations.

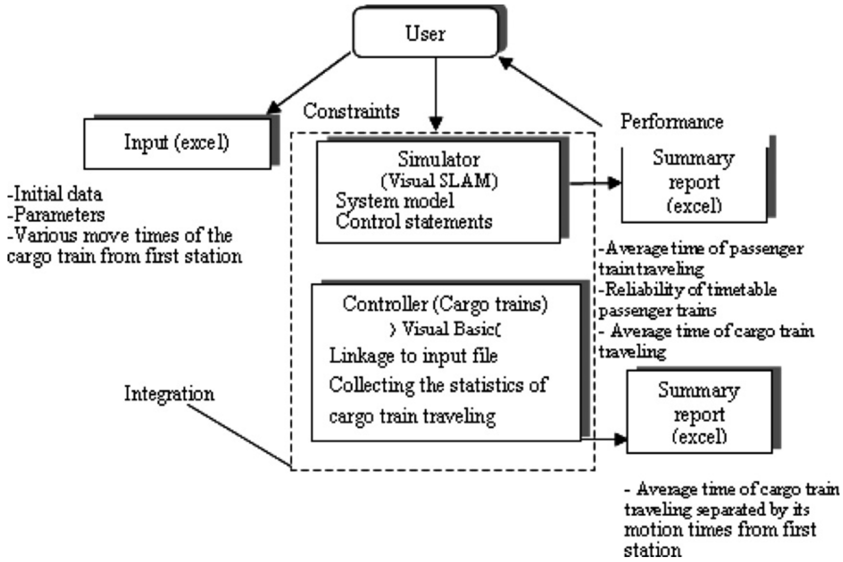

Fig. 4. Integrated simulation framework of cargo and passenger trains.

queue capacity (station lines) is not reached in station k. In addition, a cargo train is permitted to travel from j to k if it does not create a delay in movement of passenger trains from i to j.

Visual SLAM software is used to simulate the system [25]). The computer model is a fully object oriented model. The reason for employing simulation approach is the high number of stations and blocks (fifty and forty nine, respectively) that represents queues and resources, respectively. Also the computer model is linked to Visual Basic in order to obtain optimum traverse time of cargo trains. Fig. 4 illustrates the integrated simulation framework. After start-up period, the computer simulation model is executed for 172,800 min (120 day). Thus, each simulation run has been continued long enough so that reasonable estimates of means of all outputs could be obtained. For each of the 22 different scenarios, 1000 simulation run replications were made.

Simulation model of cargo and passenger train consist of a main network and a sub network. The sub network is used to apply constraints in each block. For this purpose, we used AWAIT nodes for limitations 1, 2 and STOPA function for limitation 3. The instances of the sub network object are the station names that maintained in the global string variable SZ with the argument being the number specified in LTRIB [1] of entity. The VSN is named SATION and is shown in Figs. 5 and 6 shows the main network. Arriving passenger trains are created by the CREATE node labeled as PASSENGER. At the EVENT node, Visual SLAM calls the function EVENT with JEVNT set equal 2 to record the requirement data of passenger train based on timetable. Also, Arriving cargo trains are created by the CREATE node CARGO. At the EVENT node, Visual SLAM calls the function EVENT with JEVNT set equal 3 to obtain the requirement data of cargo train. Both of type trains routed to CALLVSN node START.

The scenarios were selected by a survey from experts in the field. Furthermore, the experts have identified that the following 22 alternatives are likely to improve the existing system. (1) Automatic control of passenger trains, (2) automatic control of semi express passenger trains, (3) automatic control of express passenger trains, (4) automatic control of cargo trains, (5) utilization of expert operators for passenger trains, (6) utilization of expert operators for cargo trains, (7) utilization of expert operators for passenger trains and block overhaul, (8) utilization of expert operators for all trains, (9) existing system, (10) automatic control of all trains, (11) automatic control of passenger trains and block overhaul, (12) automatic control of passenger trains given there is blocking discipline, (13) automatic control of semi express passenger trains given there is blocking discipline, (14) automatic control of express passenger trains given there is blocking discipline, (15) automatic control of cargo trains given there is blocking discipline, (16) utilization of expert operators for passenger trains given there is blocking discipline, (17) utilization of expert operators for cargo trains given

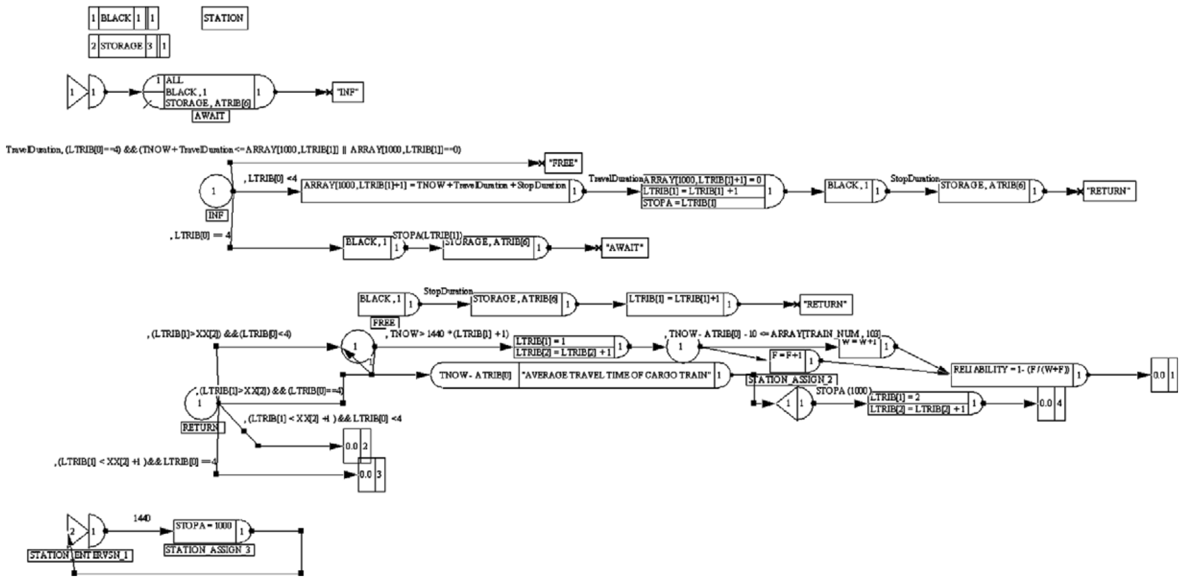

Fig. 5. Sub network of the railway system.

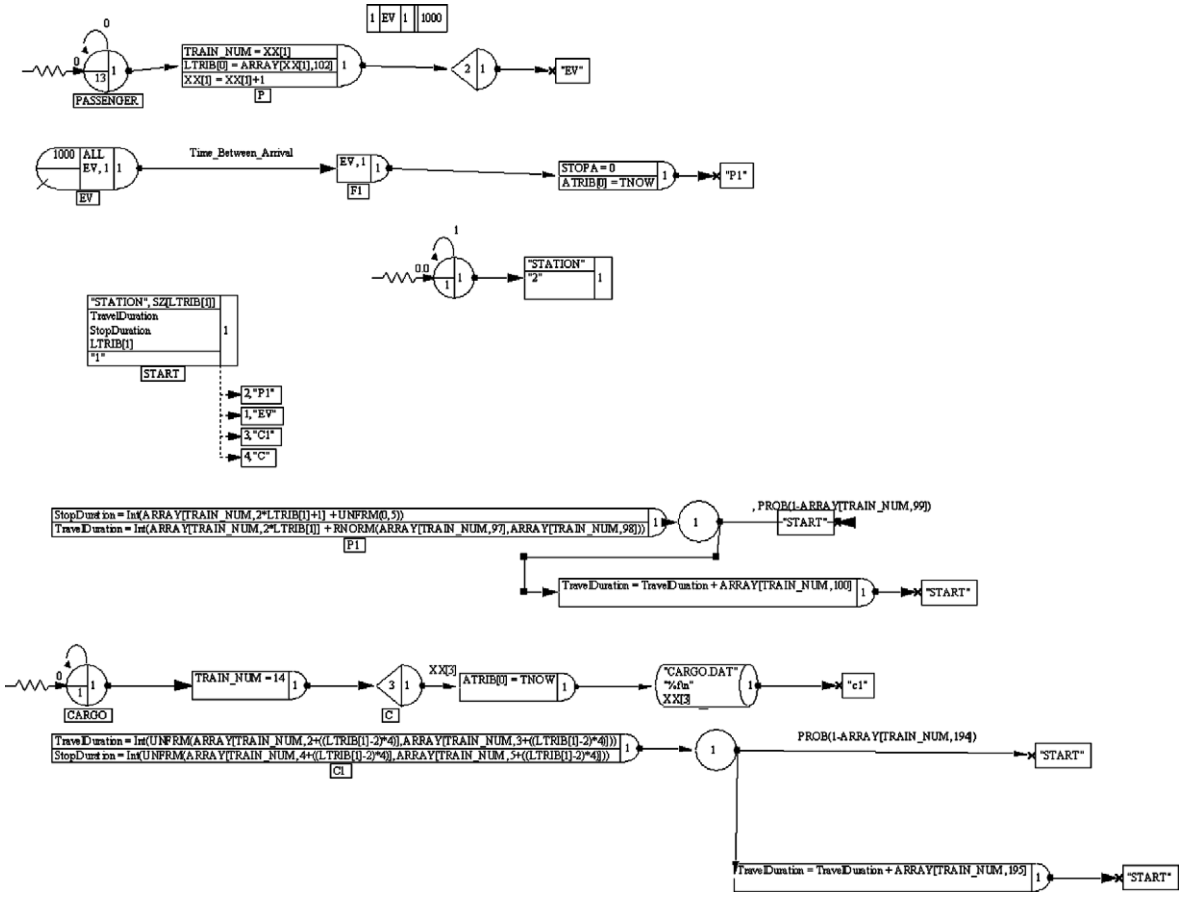

Fig. 6. Main network of the railway system.

there is blocking discipline, (18) utilization of expert operators for all trains given there are blocking discipline and block overhaul, (19) utilization of expert operators for all trains given there is blocking discipline, (20) existing system given there is blocking discipline, (21) automatic control of all passenger trains given there is blocking discipline and (22) automatic control of passenger trains given there are blocking discipline and block overhaul. The following performance measures are used to solve the problem: (A) reliability related to the timetable of the passenger trains that it defined by Sadeghi [28] as follows:

$$r = 1 - \frac{\sum_{i=1}^{m} N_i + \sum_{j=m}^{n} N_j}{n}, \quad (i \in I), (j \in J) \tag{5}$$

where N_i and N_j are

$$N_i = \begin{cases} 1 & \text{if the delay of the}\,i\text{th passenger train is greater than or equal to allowed delay} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

$$N_j = \begin{cases} 1 & \text{if the delay of the}\,j\text{th passenger train is greater than or equal to allowed delay} \\ 0 & \text{otherwise} \end{cases}$$

(B) travel time of passenger trains, (C) travel time of cargo trains, (D) unscheduled stop time of cargo trains, (E) operator errors or unauthorized speed and (F) expenses associated with new equipment installation. This paper considers E and F as qualitative criteria as their quantitative values are not available; hence, we have used AHP to assign weight for each scenario. The quantitative measures for those scenarios are shown in Table 1.

Qualitative measures were weighted by the AHP and solved by a spread sheet program. In order to avoid potential comparative inconsistency between pairs of categories, a consistency ratio (CR), an index for consistency, was calculated to assure the appropriateness of the comparisons. For the details of the CR development, readers are referred to Saaty [27]. The resulting CR values for E and F are 0.1 and 0.08, respectively. Since CR is smaller or equal than the commonly critical value of 0.1, there is no evidence of inconsistency. The resulting weights of each scenario are shown in Table 2. The values of the two criteria are based on the preliminary survey from the expert managers (see Table 3).

Table 1
Quantitative and qualitative measures obtained from simulation and AHP

Scenario	A: reliability related to the timetable of the passenger trains	B: travel time of passenger trains	C: travel time of cargo trains	D: unscheduled stop time of cargo trains	E: operator errors or unauthorized speed	F: expenses associated with new equipment installation
1	0.496	174.856	331.941	41.679	0.202887	0.020219
2	0.653	173.976	328.045	36.838	0.132904	0.100545
3	0.485	175.576	340.165	47.792	0.097772	0.027126
4	0.495	174.533	258.150	45.637	0.085682	0.030454
5	0.740	172.651	334.800	44.472	0.060810	0.044074
6	0.508	174.455	272.791	35.001	0.049254	0.025320
7	0.902	170.288	273.011	34.157	0.029852	0.115517
8	0.726	172.334	272.162	35.050	0.045091	0.068614
9	0.283	220.741	380.736	50.205	0.237374	0.016555
10	0.670	174.353	333.901	44.618	0.033820	0.229125
11	0.954	170.370	336.480	45.176	0.024553	0.322449
12	0.278	178.468	333.250	43.570	0.202887	0.020219
13	0.612	174.620	324.989	35.075	0.132904	0.100545
14	0.256	178.908	335.073	47.576	0.097772	0.027126
15	0.243	178.452	258.078	47.116	0.085682	0.030454
16	0.440	175.670	330.968	41.089	0.060810	0.044074
17	0.264	178.156	277.438	38.164	0.049254	0.025320
18	0.725	173.114	276.004	37.652	0.029852	0.115517
19	0.446	175.138	275.332	37.638	0.045091	0.068614
20	0.245	178.747	334.341	43.095	0.237374	0.016555
21	0.655	174.378	333.901	44.618	0.033820	0.229125
22	0.952	172.003	333.905	43.471	0.024553	0.322449

Table 2
The methods used for each performance measure

Alternatives	Performance measures					
	A	*B*	*C*	*D*	*E*	*F*
Simulation model	√	√	√	√		
AHP					√	√
DEA AHP Simulation	√	√	√	√	√	√

Table 3
DEA scores of the 22 scenarios

Scenario	1	2	3	4	5	6	7	8	9	10	11
DEA score	1.11	1.02	0.71	0.84	0.88	0.68	1.22	0.88	0.89	0.78	1.01
Scenario	12	13	14	15	16	17	18	19	20	21	22
DEA score	0.90	1.04	0.51	0.61	0.58	0.43	0.84	0.62	1.16	0.78	1.04

Table 2 presents methods used to calculate the performance measures for the 22 scenarios. It also shows the advantage of the integrated approach over other approach. As seen the integrated approach combines quantitative and qualitative data by computer simulation and AHP. Finally, the DEA model 4 in section 2 is employed for scoring and ranking all scenarios. For instance the extended model for scenario 1 is as follows:

$$\begin{aligned}
&\text{Min} \quad \theta_1 - \varepsilon[s_1^- + s_2^- + s_3^- + s_1^+ + s_2^+ + s_3^+] \\
&\text{s.t.} \\
&\qquad 174.856\ \theta_1 = 173.976\ \lambda_2 + 175.576\ \lambda_3 + \ldots + 174.378\ \lambda_{21} + 172.003\ \lambda_{22} + s_1^- \\
&\qquad 331.941\ \theta_1 = 328.045\ \lambda_2 + 340.165\ \lambda_3 + \ldots + 333.901\ \lambda_{21} + 333.905\ \lambda_{22} + s_2^- \\
&\qquad 41.679\ \theta_1 = 36.838\ \lambda_2 + 47.792\ \lambda_3 + \ldots + 44.618\ \lambda_{21} + 43.471\ \lambda_{22} + s_3^- \\
&\qquad 0.496 = 0.653\ \lambda_2 + 0.485\ \lambda_3 + \ldots + 0.655\ \lambda_{21} + 0.952\ \lambda_{22} + s_1^+ \\
&\qquad 0.203 = 0.133\ \lambda_2 + 0.098\ \lambda_3 + \ldots + 0.034\ \lambda_{21} + 0.025\ \lambda_{22} + s_2^+ \\
&\qquad 0.02 = 0.100\ \lambda_2 + 0.027\ \lambda_3 + \ldots + 0.229\ \lambda_{21} + 0.322\ \lambda_{22} + s_3^+ \\
&\qquad \lambda_j, s_r^+, s_i^- \geqslant 0, \quad \text{for all } j, j \neq 1.
\end{aligned} \tag{7}$$

shows the scores of all scenarios. To calculate target values, it should be found the slacks values for all inputs at first. The dual of model 2 (CCR input – oriented) which used for obtaining slack values of inputs for all scenarios is as follows:

$$\begin{aligned}
&\text{Min} \quad \theta_0 \\
&\text{s.t.} \\
&\qquad \theta_0 x_{i0} = \sum_{j=1}^{22} \lambda_j x_{ij} + s_i^-, \quad 1 \leqslant i \leqslant 3, \\
&\qquad y_{10} = \sum_{j=1}^{22} \lambda_j y_{1j} - s_1^+, \\
&\qquad wy_{r0} = \sum_{j=1}^{22} \lambda_j wy_{rj} - s_r^+, \quad 1 < r \leqslant 3, \\
&\qquad \lambda_j, s_r^+, s_i^- \geqslant 0, \forall j, j \neq 0.
\end{aligned} \tag{8}$$

For instance, target values of current system (scenario 9)'s inputs are obtained from Eqs. ((5), (9)–(11)) which are $B \cong 182$, $C \cong 340$ and $D \cong 44$.

$$x^*_{B1} = \theta^*_9 x_{B1} - s_1^{-*} = 0.89(220.7) - 15.718 = 181.624, \tag{9}$$

$$x^*_{C1} = \theta^*_9 x_{C1} - s_2^{-*} = 0.89(380.7) - 0 = 340.378), \tag{10}$$

$$x^*_{D1} = \theta^*_9 x_{D1} - s_3^{-*} = 0.89(50.2) - 1.157 = 43.737. \tag{11}$$

4. Conclusion

In summary, this paper proposed an integrated model by integration of DEA, AHP and computer simulation for complex railway systems with severe limitations, priorities and multi-objectives. The integrated model can be used for selecting optimum alternative by considering multi objectives criteria. Qualitative outputs are evaluated by AHP and then DEA is used to identify optimum alternatives. In previous study simulation and DEA are used for determining the most efficient scenario only quantitative variables are considered, while the proposed methodology simultaneously considers both quantitative and qualitative objectives. A practical case study illustrated the effectiveness of the proposed methodology. An 800-km train route system was selected. Visual SLAM language was used to develop the simulation model of the railway system. Three unique features of the railway system that are time limitations, queue priority and limited station lines are included in the simulation model. The objective of simulation model was to increase reliability related to the time table of the passenger trains, to decrease average traverse time of passenger trains and to decrease average traverse time of cargo trains. In addition, for multivariate assessment of the alternatives by DEA, safety and cost factors were derived and considered from an AHP analysis. Also, DEA is used for optimization of current system. This paper presented a unique integrated approach for performance improvement and optimization of railway systems with complex limitations which require both qualitative and quantitative assessments. Previous studies use simulation and DEA based on quantitative variables for identification of the most efficient scenarios, while this study considers both quantitative and qualitative variables for efficiency assessment and performance optimization by integration of simulation, DEA and AHP. This is quite important for systems where some of their performance measures are qualitative such as railway and production systems. The integrated modeling approach illustrated and explained in this paper can be used to solve other real world problems.

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