

TWO STAGE MULTIPLE ATTRIBUTE DECISION MAKING PROBLEM IN IRANIAN GAS DISTRIBUTION SYSTEMS

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Abstract The purpose of this paper is to present the possibility of replacing physical unit cost in transportation or distribution problems by an aggregate coefficient, getting qualitative and subjective considerations involved. The model for constructing aggregate cost is a two stage multiple attribute decision-making problems. In the first stage supply points, demand points and routes of transportation are alternatives and have to be weighted against their own attributes. In the second stage, the alternatives are placed as attributes in a new matrix and the unit aggregate costs will be the new alternatives. Some heuristic techniques are developed for tradeoffs between attributes. Experts and decision-makers do tradeoff. The results are compared with the simple physical costs.

Key Words Aggregate Cost, Multiple Attributes, Distribution

چکیده هدف این مقاله ارائه نتایج تحقیق در مورد جانشینی عامل هزینه در مسائل حمل و نقل و توزیع با یک ضریب ادغامی است که علاوه بر هزینه فیزیکی ملاحظات نظری و محدودیت های خاص منابع، نقاط مصرف و مسیرهای توزیع را نیز ملحوظ نماید. در این روش عامل هزینه واحد حمل و نقل که در روشهای فعلی عاملی تعیین کننده در بهینه سازی توزیع می باشد جای خود را به هزینه ادغامی می دهد. تمام ملاحظات کیفی برای منابع، نقاط مصرف و نیز مسیر حمل و نقل مواد در این هزینه ادغامی منظور می گردد. این هزینه واقعی تر از هزینه معمولی است زیرا هزینه های فرصت و هزینه های خارجی را به خوبی منعکس می کند. کاربرد این هزینه در حل مسائل توزیع به جوابهای واقعی تری منجر می گردد. مدل عبارت است از یک مسئله تصمیم گیری چند معیاره دو مرحله ای. روش دو مرحله ای این فرصت را می دهد که معیارهای کیفی منابع، نقاط مصرف و مسیر، جداگانه و توسط کارشناسان و تصمیم گیران مربوط مورد ارزیابی قرار گیرد. هزینه های ادغامی حاصل جایگزین هزینه های معمولی در معادلات بهینه سازی مسائل توزیع می گردند. نتیجه نشان می دهد که هزینه های ادغامی با هزینه های معمولی اختلاف قابل توجه دارند و در بسیاری موارد به پاسخ های مختلف منجر می شوند.

1. INTRODUCTION

The unit cost in classical transportation, distribution design and facility location have been the sole dominant in finding optimal solution for many years of academic works and project implementation. In this paper we are focused on qualitative aspects of supply, demand zones and routes. These together with the physical cost of transportation will be our new criteria for finding optimal way of source allocation or distribution problems. A two stage

multiple attribute decision making method (TSMADM) is introduced for covering all requirements for an exact analysis of extrinsic factors in large scale distribution problems in real world. An overview of distribution models reveals that cost has been a sole dominant in determining the best way of distributing commodities among demanders. Of course many editors have found it suitable to use some qualitative factors in cost structure to comply with the effect of various external factors. Arntzen, Brown and Harrison [1] have considered local

TABLE 1. Aggregate Cost Concept.

ELEMENTS OF AGGREGATE COST	Attributes corresponding to each element				
Sources	C_{11}	C_{12}	C_{13}	...	C_{1s}
Demands	C_{21}	C_{22}	C_{23}	...	C_{2d}
Routes	C_{31}	C_{32}	C_{33}	...	C_{3r}

content requirements in distribution systems and Wlodzimierz Ogryczak [2] have incorporated qualitative aspects of cost element in location and distribution problems. Frank Plasteria [3] has suggested consumer utilities as a criterion to be also considered in distribution problem other than cost. All of these endeavors are symptoms of necessity for considering qualitative aspects of supply, demand points and routes. In this paper all major qualitative factors are fed to the model for considering the increasing needs for attention to fast changing economy, environment and technology.

Carrizosa and Conde [4] in their locating model assume the cost as a function of the network distances to users. But in an extension they use Weber's problem to locate a facility in the Euclidean plane in order to minimize the sum of its (weighted) distances to the locations of a given set of users.

Pino et al. [5] have estimated a system of equations for distance function and cost shares and consider labor and capital as cost criteria. In the production-distribution models, Dasci and Verter [6] show that a few researchers have employed various extrinsic criteria for decision-making. Of course only some of important factors have been considered. In the mathematical models and operations research textbooks the sources and destinations with high or low priority are given a big or small cost value to be considered properly in decision-making. In this paper we have assumed the cost not only as a function of distance but also a function of all major extrinsic variables like technology, government policy and environmental impacts.

The paper has been organized in five sections. The first section is devoted to introducing TSMADM.

In second section the new aggregate cost element is formulated. Calculation for aggregate costs will be presented in section three through an example. In section four related models are compared. The conclusion will be presented in section five.

2. TWO STAGE MULTIPLE ATTRIBUTE DECISION MAKING

In many cases in transportation and distribution problems, suppliers that have to cover planned demands, have not the same qualitative levels. The demand zones also differs when qualitative parameters are taken into account. These differences are crucial to decision makers when hard policies have to be considered for allocating sources to demand points.

Qualitative decision making elements for supply zones, demand areas and the routes between are shown in Table 1. This is a three element aggregate cost concept.

For each alternative of distributing supply to demand points there are (s+d+r) criteria. The proposed method takes these criteria as the components of aggregate qualitative cost. Sources, demand points and routes are the first stage alternatives. They are ranked against their own criteria. The second stage alternatives, which are various competitors for supplying individuale demand points, are compared based on above-mentioned three main elements of aggregate qualitative cost. In the next section we formulate the method. We have to notice that this method differs from AHP [7] because each of the first stage alternatives (for example various sources) has its own attributes

TABLE 2. The Second Stage MADM.

Second Stage Alternatives	Second stage attributes		
	Supply points	Demand points	Routes
A_1	X_{11}	X_{12}	X_{13}
A_2	X_{21}	X_{22}	X_{23}
\vdots	\vdots	\vdots	\vdots
A_m	X_{m1}	X_{m2}	X_{m3}

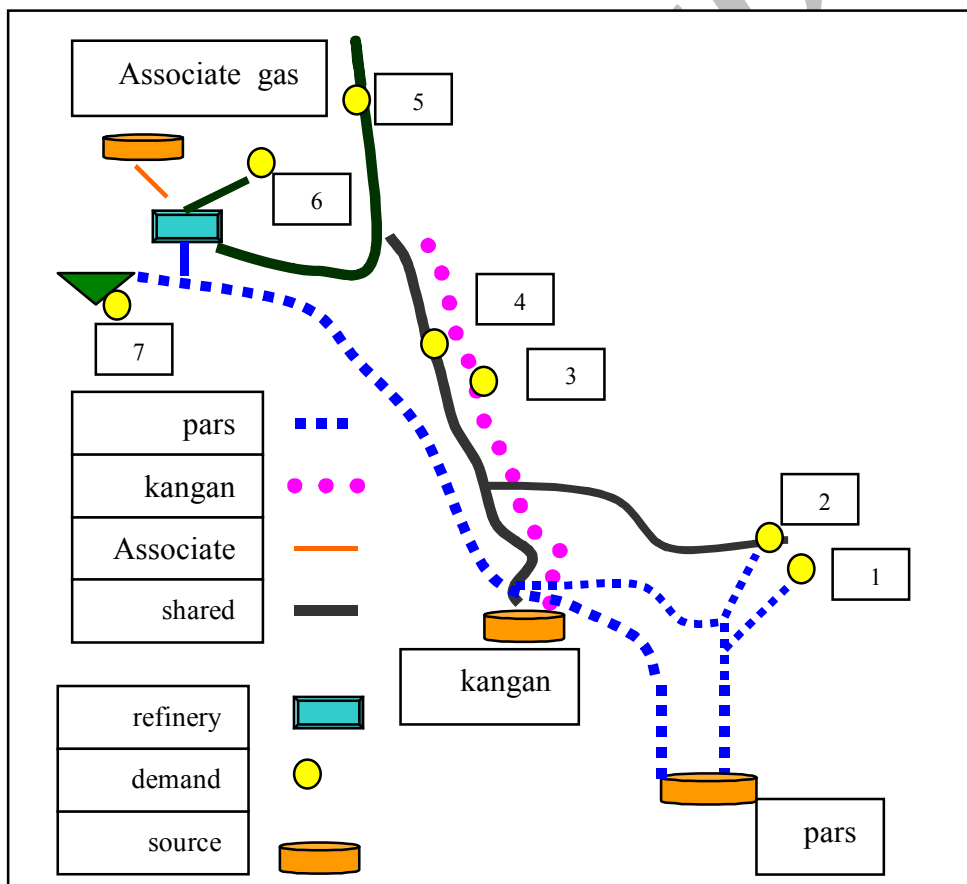


Figure 1. Natural gas distribution in Southern Iran.

which are not applicable for the others. In other words the attributes are not common for all alternatives to allow us for constructing hierarchical system.

Therefore in the second stage of problem we have a number of possible choices each containing one supply point, one demand point and a proposed route between.

TABLE 3. Pairwise Comparisons Between Supply Attributes.

	Development	Environment	Byproducts	Urgency
Development	1	2	1/2	1/3
Environment	1/2	1	1/3	1/5
Byproducts	2	3	1	1/2
Urgency	3	5	2	1

TABLE 4. Pairwise Comparisons Between Demand Attributes.

	Export	Region. prior.	Environ. impact	Substitution
Export	1	1/2	2	1/3
Region. priori.	2	1	4	1
Environ. impact	1/2	1/4	1	1/5
Substitution	3	1	5	1

3. TWO STAGE MADM FORMULATION

After incorporating MADM proper methods for each row in Table 1, the first stage of solution is terminated and each of three sets of alternatives are ranked. We have used pair wise comparison matrix to assess the relative contribution of supply and demand alternatives for each related attribute. In the second stage for each alternative the number of criteria is three: supply, demand and route. Table 2 shows the second stage of MADM problem.

Contribution of alternatives for each related attribute would be available by use of pair wise comparison matrix. The next step is to link quantitative data to physical cost of each second stage alternative so that we could add qualitative and quantitative figures to each other. Selecting an attribute, which is better exchanged to quantitative figures, should do this. The quantitative values of other attributes are proportionally calculated based on comparative data. A better way is to refer to the first stage attributes to find which are more tangible and changeable to quantitative figures.

This will be clear in the following example.

4. AN APPLICATION EXAMPLE

Figure 1 shows a distribution system for supplying natural gas to demand points in south of Iran. There are 3 supply points (Pars, Nar and Kangan, Associated gas field), 7 demand points (Southeast, Jahrom, Shiraz, Central and Western, Esfahan, Northwest export and injection in Aghajari) and 12 transportation routes involved in the natural gas distribution among selected areas.

Tables 3 and 4 show the attributes of sources and demand points respectively and evaluated numbers for them. The values have been calculated based on the results of two questionnaires prepared for the job. The questionnaires on supply and demand were designed for getting comments from decision makers through subjective pair wise comparisons. The weight of each first stage attributes can be calculated through eigenvector method.

TABLE 5. Comparison of Supply Points with Respect to Development Potential.

	S1	S2	S3	S_d^T
S1	1	2	4	0.56
S2	1/2	1	3	0.32
S3	1/2	1/3	1	0.12

TABLE 6. Comparison of Demand Points with Respect to Substitution Potential.

	D1	D2	D3	D4	D5	D6	D7	D_s^T
D1	1	2	3	2	1/2	4	1/3	0.113
D2	1/2	1	1/2	1	5	3	1/6	0.127
D3	1/3	2	1	3/2	5	1	1/8	0.140
D4	1/2	1	2/3	1	1/3	3	1/5	0.060
D5	2	1/5	1/5	3	1	6	1	0.134
D6	1/4	1/3	1	1/3	1/6	1	1/8	0.037
D7	3	6	8	5	1	8	1	0.37

Only one qualitative attribute has been considered for routes in this example.

The quantitative attribute for distribution system is cost per one cubic meter of natural gas distributed to demanders. This includes production, refining, transmission and distribution costs. The four major qualitative attributes for supply areas are: development level [8], environment protection requirements, by products recovery and urgent on gas withdrawal. The demand attributes are: regional priorities, environment protection requirements [9], export potential and substitution advantages and the criterion for routes is environment protection requirements. For supply and demand attributes the pair wise comparisons have been done through questionnaires answered by experts and shown in Tables 3 and 4. The λ_{max} values by using eigenvector method for these tables are 4.01 and 4.02 respectively and the weights of the attributes for supply and demand are as follows: $W_s = (0.157, 0.088, 0.272, 0.483)$ and $W_d = (0.158, 0.35, 0.083, 0.41)$.

Tables 5 and 6 show comparisons of supply and

demand points with respect to one of their relative attributes. The results of comparisons are put in two vectors: $S_d^T = (0.56, 0.32, 0.12)$ for supply and $D_s^T = (0.113, 0.127, 0.14, 0.08, 0.134, 0.037, 0.37)$ for demand. The same calculation is done for the other attributes.

The results for the other attributes can be viewed in matrices M and N.

The first column of matrix M, stands for development attribute and so on. This is the same for matrix N and demand attributes. Matrix O, stands for routes single criteria.

It worth to mention that each column is obtained by judgments from experts and DM's directly engaged in the subject. It is one of the advantages of this method.

$$\lambda_{max} = \begin{matrix} 3.36 & 3.0 & 3.1 & 2.99 \\ \text{Develop.} & \text{Environ.} & \text{Urgence} & \text{Byprod.} \end{matrix}$$

$$M = \begin{matrix} \left| \begin{matrix} S1 & 0.56 & 0.3 & 0.54 & 0.7 \\ S2 & 0.32 & 0.54 & 0.3 & 0.19 \\ S3 & 0.12 & 0.16 & 0.16 & 0.11 \end{matrix} \right| \end{matrix}$$

TABLE 7. Decision Matrix for Determining Aggregate Qualitative Cost.

Choice	Supply (attributes)	Demand (attributes)	Routes	Total
A1	1.54, 0.86, 1.52, -2	3.24,5.4,-10.74,-3.39	2.49	-1.08
A2	1.54, 0.86, 1.52, -2	3.81,4.47,-3.06,-2.4	0.54	5.28
A3	1.54, 0.86, 1.52, -2	4.2,2.88,-6.12,-2.4	0.50	0.98
A4	1.54, 0.86, 1.52, -2	4.02,4.74,-1.68,-3.06	0.50	6.44
A5	1.54, 0.86, 1.52, -2	1.11,1.95,-6.45,-1.8	0.79	-2.48
A6	1.54, 0.86, 1.52, -2	11.1,2.28,-3.63,-9.96	0.28	1.99
A7	0.91,1.54,0.86,-0.54	3.81,4.47,-3.06,-2.4	0.58	6.17
A8	0.91,1.54,0.86,-0.54	4.2,2.88,-6.12,-2.4	0.46	1.79
A9	0.91,1.54,0.86,-0.54	2.4,2.64,-3.6,-7.05	0.42	-2.38
A10	0.34,0.46,0.46,-0.31	4.02,4.74,-1.68,-3.06	0.55	5.48
A11	0.34,0.46,0.46,-0.31	1.11,1.95,-6.45,-1.8	0.42	-3.82
A12	0.34,0.46,0.46,-0.31	11.1,2.28,-3.63,-9.96	0.71	2.45

TABLE 8. Results of Second Stage MADM.

Alternative	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Qualitative cost	-1.08	5.28	0.98	6.4 4	-2.5	2	6.1 7	1.8	-2.4	5.48	-3.82	2.45
Physical cost	7	6.5	6	5.5	7.5	7	6.8	7.1	6.9	5	7.2	6.8
Total cost	5.9	11.8	7	11	5	9	13	8.9	4.5	10.5	3.4	9.25

$\lambda_{max.} =$	7.16	7.22	8.02	9.24
	<i>reg. pro.</i>	<i>substi.</i>	<i>export</i>	<i>environ.</i>
N =	D1 0.113	0.358	0.18	0.108
	D2 0.127	0.149	0.102	0.08
	D3 0.14	0.096	0.204	0.08
	D4 0.08	0.088	0.120	0.235
	D5 0.134	0.158	0.056	0.102
	D6 0.037	0.065	0.215	0.06
	D7 0.37	0.076	0.121	0.332

O = (R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12) = (0.3, 0.065, 0.06, 0.06, 0.095, 0.034, 0.07, 0.055, 0.05, 0.066, 0.05, 0.085)

In matrices M and N and O, the figures for attributes are comparative and need to be comparable with quantitative unit cost of distribution network. For each matrix the candidate attribute that is better changed to quantities is selected. For supply, by products and for demand, substitution is the best. Also for each of these two criteria the more suitable

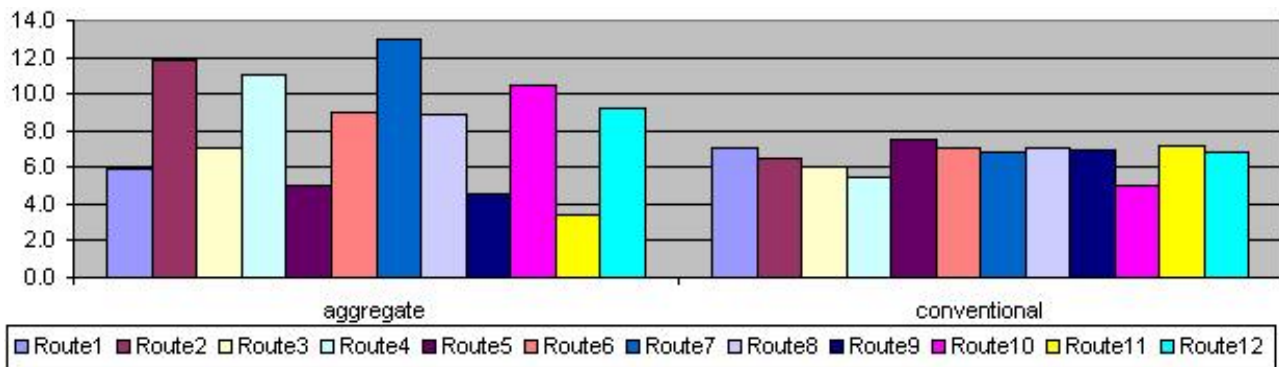


Figure 2. Difference between physical and aggregate cost.

supply point and demand zone are identified. S1 (Pars field) and D3 (Shiraz) are the best. In this case routes criterion is changed to quantities regarding environmental attributes of supply and demands. The byproducts value for Pars field are evaluated about 2 cent per cubic meter of produced natural gas and the Shiraz substitution benefit is around 2.4 cent/M3. These two figures are corresponding to 0.7 and 0.08 in matrices M and N. Proportionally all other values in matrices are changed to money (matrices M1, N1 and O1). Environmental requirements for the route in choice A3 is estimated around 0.5 cent/M3 transported gas. Table 7 shows the new values of alternatives via 12 different choices.

	<i>Develop.</i>	<i>Environ.</i>	<i>Urgence</i>	<i>Byprod.</i>	
$M1 =$	S1	1.54	0.86	1.52	2
	S2	0.91	1.54	0.86	0.54
	S3	0.34	0.46	0.46	0.31
	<i>reg. pro.</i>	<i>environ.</i>	<i>export</i>	<i>substi.</i>	
$N1 =$	D1	3.24	5.4	10.74	3.39
	D2	3.81	4.47	3.06	2.4
	D3	4.2	2.88	6.12	2.4
	D4	2.4	2.64	3.6	7.05
	D5	4.02	4.74	1.68	3.06
	D6	1.11	1.95	6.45	1.8
	D7	11.1	2.28	3.63	9.96

O1 = (R1, R2, R3, R4, R5, R6, R7, R8, R9, R10,

R11, R12) = (2.49, 0.54, 0.5, 0.5, 0.79, 0.28, 0.58, 0.46, 0.42, 0.55, 0.42, 0.71)

The net result of supply, demand and routes attributes tradeoff is added to unit cost of each distribution choice (Table 7). It is worth to mention that A1 to A12 are the second stage alternatives. This vector takes the role of unit cost in transportation and distribution problems where subjective attributes on start and end points and the routes are important for decision makers.

Figure 2 shows the difference between physical and aggregate cost. It depicts that in most cases the two costs differ drastically. In Table 8 for alternative A11 difference between physical and aggregate cost, which is mainly for export opportunity is of importance. It appears that A7 has the biggest aggregate cost. For this alternative export and substitution advantage is not considerable. A7 shows an addition of 6.17 cent per cubic meter of natural gas for involvement of qualitative attributes. The aggregate cost appears as a cost coefficient in distribution problems. One interesting finding is that the range of aggregate cost dominates that of physical cost. It is 8.94 against 2.5 (Table 8). The averages are 8.27 and 6.6 respectively. We came to this result that the real cost is more than the cost used to be calculated in feasibility studies and decision making problems in this case. We have incorporated Lingo software for solving the problem of natural gas distribution to Southern and Central Iran (Figure 1). The results are shown in Figure 3 for aggregate cost and Figure 4 for physical (conventional) cost. The sources and demands capacities are in million cubic meters

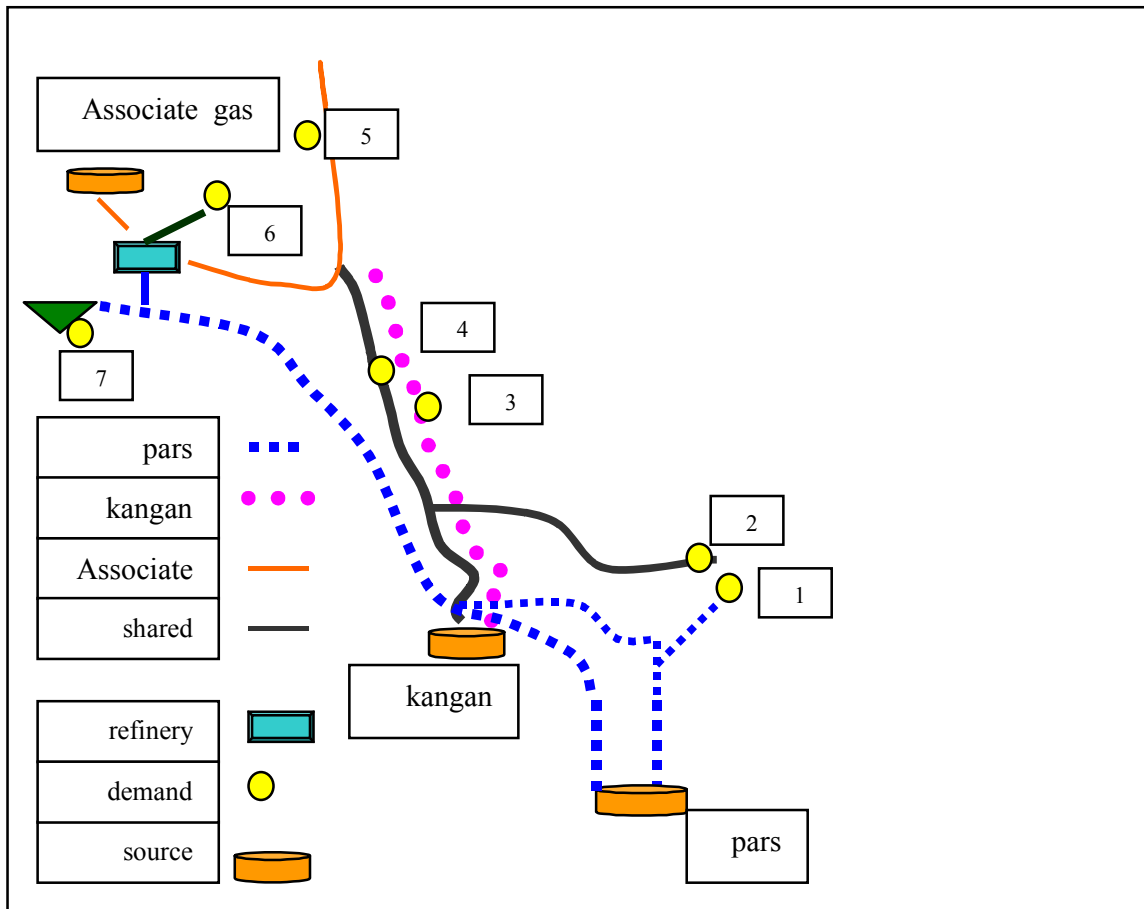


Figure 3. Natural gas distribution in Southern Iran (case1, physical cost).

per day of natural gas and equal to $S = (125,90,30)$ and $D=(25,27,42,47,20,30,50)$. The unit costs are as in table 8. In Figure 3 (based on physical cost) the rejected alternatives are (A2, A4, A9), while for the case of aggregate cost (Figure 4) the removed alternatives will be (A3, A5, A7, A10, A12).

5. COMPARISON

The models applied for distribution problems have not been focused on the nature of large-scale industries when long-term consideration is of high importance. The extrinsic criteria are essential for allocating sources between various consumers. In

some of these models only part of extrinsic criteria have been considered like price uncertainty, tariffs and exchange rate uncertainty.

Priority policy involved in the model has been implied in many industries like power plants, oil and gas industry. Applying two-stage model has its merit for easing problem solving when compared with models dealing with a large number of attributes and demanding sophisticated mathematical method with high possibility of error.

The system dynamics methods [10] can be applied to construct the aggregate cost curves for long term considerations. The weakness of this method will be prediction formulation errors.

The most important disadvantage of TSMADM is that the collecting data will be time consumer because more experts have to be interviewed for

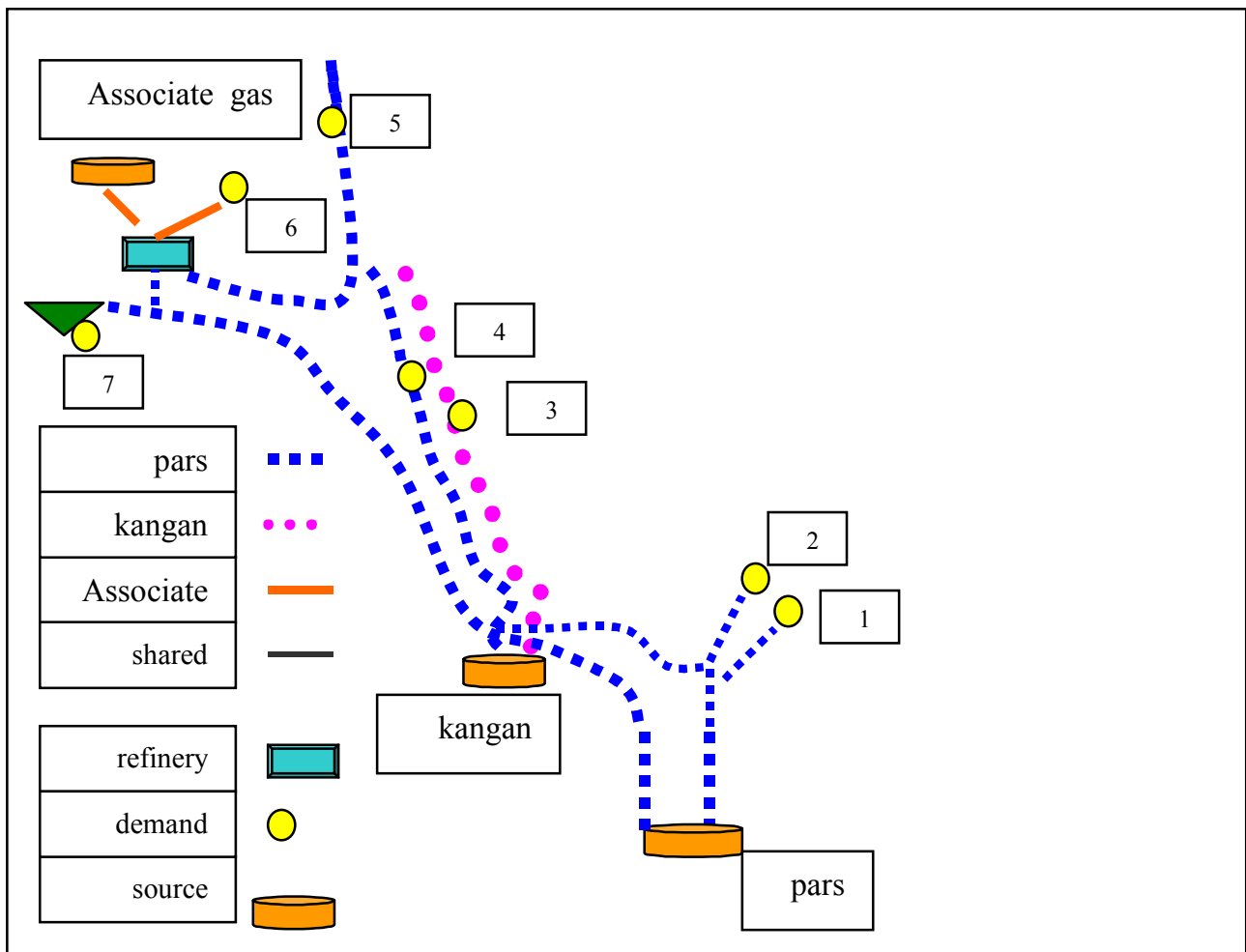


Figure 4. Natural gas distribution in Southern Iran (Case 2, conventional cost).

subjective information.

6. CONCLUSION

The existence of hidden effects of long term and macroeconomic parameters on decisions taken for selecting the best distribution pattern justifies that the aggregate costs is more reliable than physical costs especially when we are going to set a long term planning. It means that in a number of alternatives the external impacts are important and may affect the decisions accuracy. A part of post optimality analysis for distribution problems will be conducted

through incorporating two stages MADM model by changing or altering attributes without affecting the main structure of optimization models formulation.

Considering supply, demand and routes as separate fields of expertise help us to get the best results for comparisons on attributes or weighting alternatives. The number of attributes shrinks significantly because of breaking the decision in two stages. In the example we have comparisons in groups with maximum 4 attributes instead of a comparison between 9 attributes. In large-scale problems this advantage will be more highlighted. In energy section, the extrinsic aspects of supply demand points and routes are more controversial

than the cost of physical installations. The method has considered this case in its best way.

One strength point of the paper is making tradeoffs with cost which is tangible for supply and demand experts and DM's. The breakdown to attributes has made tradeoffs with cost more meaningful than trading off the supply and demand levels directly with cost.

This study makes clear the concept of Extrinsic Values [11] for commodities like natural gas, which are not renewable and stored in different geographical location. The opportunity cost of supplying commodities to demanders will also be clarified.

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