SYSTEMS MODELING FOR OPTIMUM PLANT LOCATION: ASEAN REGIONAL INDUSTRIAL PROJECTS

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I. INTRODUCTION

USHERING in a new era of regional economic cooperation, the first summit meeting of ASEAN heads of state in February 1976 has spawned active negotiations among member countries to undertake a wide range of co-operative economic activities.[1] One significant agreement is the decision to adopt the first package of regional industrial projects, involving the production of urea in Indonesia and Malaysia, phosphate fertilizer in the Philippines, diesel engines in Singapore and soda ash in Thailand. ASEAN has thus moved to establish an industrial complementation scheme by which to allocate industrialization of certain products to individual member countries.

Very broadly speaking, the normal operating of an open market system will result in, among other things, optimal locational distribution of production activities. ASEAN countries had tended to rely on these natural forces with limited though varying degrees of government interference. National boundaries and their associated trade barriers, however, constrict the size of markets, acting in much the same way as high transportation costs. The constrained potential market may be too small to justify otherwise desirable manufacturing processes of efficient scale—hence one of the principal justifications for economic integration. Nonetheless, efforts within ASEAN to assign certain industries to specific countries seem to imply doubt that "equitable" specialization would follow from market forces responding unaided to tariffs and other trade barriers.

Governmental intervention in market mechanisms to some degree is wide-spread, with deep-rooted reasons [2, pp. 339–61]. Developing nations argue that wasteful multiplication of industrial plants working below capacity is not necessarily prevented by market forces. Many advocate government action to achieve the maximum effect of scale economies and specialization. Also, developing countries feel the market itself would cause industrial activity to gravitate toward the more advanced members of a trade association. Again, intervention is viewed necessary to ensure a fairer distribution of employment and income generation.

These considerations are of course arguable, but nevertheless present the pragmatic basis for project dispensation within a cooperative group of countries. The obvious costs and disadvantages to such agreed specialization and allocation

[1] See [5] for an insightful analysis of ASEAN development and [1] for recent cooperative economic activities.

could be significant[2] unless tempered by some reference to economic criteria. Most of the ASEAN complementation scheme projects seem to be based on the availability of raw materials, and reportedly exhibit considerable scale economies. As the package agreement expands, however, industries of a more "foot-loose" nature will be involved in discussions. Absolute, if not comparative, cost advantages thus bear careful consideration, along with the illusive concept of equity.

This paper demonstrates the application of a linear programing model to the problem of selecting minimum cost plant locations for each stage of production of a given industry. The analysis depends on the quantity of the product demanded in each member country, the cost of production at each plant and the cost of transportation between countries. It is assumed that these products are characterized by scale economies, exploitation of which may be constrained by the smallness of individual domestic markets, and thus may require an expanded regional market. Member countries are too small to affect world prices, and an appropriate level of protection to ensure regional production is assumed.

This paper is not an analysis of the previously mentioned five assigned ASEAN industrial projects. Rather, a few illustrative results from the model are presented using data on steel billet, pulp and paper, cement, and urea fertilizer.

II. THE MODEL

We use a mixed-integer programing model patterned closely on one developed by Carnoy [3] for application to Latin American data. Each industry is decomposed into several serially related stages. We then seek to minimize the total cost of producing the final product, subject to constraints ensuring that (1) final demand for the industry will be met in each country from domestic production, imports, or both; (2) enough raw materials will be available to satisfy requirements of the final product; and (3) production in each plant will not exceed capacity. The minimal cost program indicates the model's optimal location of plants within the region, given final demand, shipping costs and direct manufacturing expenses.

Assume that costs of production at each plant can be written as a simple linear function of output. A plant producing stage s product in country i for shipment to country j will thus have costs

$$C_{ij}^s(q^s)=a_i^s+\sum_j c_{ij}^s q_{ij}^s,$$

where a_i^s represents fixed costs of producing in i; c_{ij}^s is manufacturing costs plus, if $i \neq j$, shipping costs per unit produced in i and shipped to j; and q_{ij}^s denotes the quantity produced in i and shipped to j (including that for domestic use, when $i=j$).

[2] Moreover, with country designation made before the completion of general feasibility studies, political consideration inevitably plays a strong role. The studies themselves can easily be biased toward supporting the existing assignments. In applying research results, it will be difficult to discard an industry found impractical when nationalistic interests intervene.

However, the optimal program will not, in general, specify plants for every product in every country. Whenever $q_{ij}=0$, country i will have no plant for the product, and a_i^s will be zero also. Alternatively, if the optimal program indicates that several plants should be built in a given country, then fixed costs are some integer multiple of a_i^s. To this end, we introduce an integer variable $w_i^s=0$, 1, 2, . . . into the cost functions, representing the number of plants built in country i. Hence fixed costs affect the objective function in the amount $a_i^s w_i^s$. Total cost of satisfying demand for the final product throughout the ASEAN region, which we seek to minimize, can thus be stated as

$$C=\sum_i(a_i^1 w_i^1+\sum_j c_{ij}^1 q_{ij}^1)+\sum_i(a_i^2 w_i^2+\sum_j c_{ij}^2 q_{ij}^2)+\cdots$$
$$+\sum_i(a_i^n w_i^n+\sum_j c_{ij}^n q_{ij}^n), \qquad (1)$$

where $s=n$ designates the final product, and $s=1, 2, \ldots, n-1$ denote intermediate goods. A set of constraints noted below assures that $w_i^s>0$ if and only if $q_{ij}^s>0$.

The model requires the assumption that all plants within a given country will have the same capacity Q_i^s. Due to data limitations, we further assume that all plants, wherever located, have the same capacity, although some idea of the effects of various sizes of plants is investigated parametrically. The constraint

$$w_i^s Q_i^s-\sum_j q_{ij}^s \geqq 0 \qquad \text{(for each } i \text{ and each } s), \qquad (2)$$

together with the nonnegativity constraints on w_i^s and q_{ij}^s, ensures that production in country i, $\sum_j q_{ij}^s$, remains within bounds of that country's capacity, and that only if w_i^s is a strictly positive integer will $q_{ij}^s>0$.

To assure that production in ASEAN as a whole meets final demand requirements of each country, we constrain

$$\sum_i q_{ij}^n=f_j^n \qquad \text{(for each } j), \qquad (3)$$

where f_j^n denotes exogenously estimated demand for the final product n in country j.

Assuming that production relationships between any two successive stages are linear with fixed coefficients, the model specifies that

$$\sum_i(q_{ij}^s/\alpha_{ij}^s)=\sum_k q_{jk}^{s+1} \qquad \text{(for all } j),$$

where $1/\alpha_{ij}^s$ is the amount of q_{ij}^s required per unit of q_{ij}^{s+1} produced. This constraint requires simply that input requirements for raw materials be satisfied. Data limitations for this preliminary study require us to take the input-output coefficients $1/\alpha_{ij}^s$ to be the same in all countries, so this last constraint can be further simplified to

$$\sum_i q_{ij}^s-\alpha_j^s\sum_k q_{jk}^{s+1}=0 \qquad \text{(for each } j). \qquad (4)$$

The model thus consists of equations (1)–(4) plus the nonnegativity constraints

$$q_{ij}^s\geqq 0 \qquad \text{(for all } i, j, \text{ and } s),$$
$$w_i^s=0, 1, 2, \cdots \qquad (5)$$

III. THE DATA AND OPTIMIZATION RESULTS

We have chosen four industries to present here: steel billets, pulp and paper, cement, and urea fertilizer. The production of each is visualized in several segments. Steel billet, used in producing bars, rods and wire, requires the input of steel ingots, which in turn utilizes pig iron. In pulp and paper, we consider pulp as an input to both newsprint and writing paper. Urea fertilizer has two production stages, ammonia and urea, while cement is treated as a single-stage industry. We present the steel industry data in some detail to illustrate the type of data and procedures used to adapt it (although this industry's cost saving from regional production turns out to be the smallest of all industries considered in this paper).

As described, the three segments of the steel industry are serially related. Taking AIDC [7, pp. 270–72] estimates of the interstage requirements α^s in equation (4), each ton of billet requires 1,111 kilograms of ingot and each ton of ingot requires 909 kilograms of pig iron. Two levels of excess demand for the final product are shown in Table I. The level I assumption is extracted directly from the AIS's projections for 1985.[3] To reveal the impact of a considerably larger magnitude of aggregate regional demand, our level II assumption specifies one-half the projections of demand for crude steel in 1985 [8, p. 757]. Capacity levels Q^s in equation (2) are also taken from the AIS report, and represent the levels of annual output for which investment costs were estimated, one and two million tons per year.

Finally in estimating the cost function coefficients a_i^s and c_{ij}^s in equation (1), available data does not differentiate between countries. Hence the a_i^s's are the same for all countries i for product s, and the c_{ij}^s's differ only by transportation costs.[4] Setting aside transport costs for the moment, we estimate manufacturing costs as linear segments, each of which connects two adjacent points in the

TABLE I

ASEAN Excess Demand Levels: Steel Billets, 1985

(1,000 tons)

Country	Level I	Level II	II÷I
Indonesia	273	806	2.95
Malaysia	140	685	4.89
Philippines	150	1,315	8.77
Singapore	100	1,425	14.25
Thailand	250	1,007	4.03
Total	913	5,238	5.74

Sources: Taken from AIS [8, p. 759] for level I; level II derived as described in text.

[3] See [8, p. 759]. The projections are derived mainly from a cross-sectional linear regression of per capita GDP on per capita steel consumption.

[4] The particular cost figures we use here were estimated by AIS for a hypothetical plant located in Singapore.

TABLE II
STEEL INDUSTRY COSTS

Annual Capacity (1,000 tons/year)	Cost Function
Pig Iron:	
1,000	$0.867+47.43\ q_{ij}^1$
2,000	$6.6\ +41.7\ q_{ij}^1$
Steel Ingots:	
1,000	$0.52\ +20.78\ q_{ij}^2$
2,000	$2.62\ +18.45\ q_{ij}^2$
Steel Billet:	
1,000	$0.727+24.29\ q_{ij}^3$
2,000	$4.24\ +20.78\ q_{ij}^3$

Sources: Derived from data in AIDC [7, (4)/14, pp. 270–72].
Note: Slope coefficients adjusted by shipping costs between i and j.

capacity-total cost space. Thus the second equation in each category of Table II represents the line connecting total cost estimates for plants with the capacity of one and two million tons per year; the first equation connects plants of a quarter-million and one million tons. The intercept of each segment represents fixed costs of one plant of the stated capacity, and the slope serves as unit costs of manufacturing.

The capacity-total cost points from which these equations were derived were first adjusted to net out costs of the prior stage raw materials: the cost of pig iron was excluded from that of ingots, for example, before deriving the ingots functions shown in Table II. Also, the slope coefficients in Table II must be adjusted by adding shipping costs for each a_{ij}^s, $i \neq j$. The final result is the data for c_{ij}^s in equation (1). Transport cost data for steel products appear in Table III. Note that since data limitations force us to adopt the unrealistic assumption that costs are equal in all five ASEAN countries, the resulting optimal plant location decisions are, in effect, dictated solely by transport costs. We further take transport costs to be the same for all three steel products.

Results[5] for the steel industry appear in Table IV, which shows production levels by country, and Table V, which illustrates the pattern of shipping implied by an optimal solution for level I excess demand. As can be seen from Table I, expanding final demand from level I to level II involves 5.7-fold increase. Total costs of meeting excess demand rise slightly less, by a factor of 5.3. At level I, Malaysia supplies none of its own pig iron, and Singapore imports all its needs for all three products. At the much higher demand implied by level II, however, and given the one-million ton scale of operation assumed for Table IV, every

[5] Solutions here were obtained on an IBM 370/145 at the Asian Institute of Technology (Bangkok), Regional Computing Center using IBM's mathematical programing package MPSX/370 with the mixed-integer feature MIP/370. This program uses a branch-and-bound algorithm, with several optional search rules available. However, these solutions used only the standard solution strategy.

TABLE III

TRANSPORT COST (DISTANCE): PIG IRON, INGOTS, AND BILLETS

($/ton)

	Malaysia	Philippines	Singapore	Thailand
Indonesia	5.9 (893)	7.6 (1,559)	4.5 (526)	6.9 (1,291)
Malaysia		8.0 (1,697)	4.3 (1,367)	6.7 (1,209)
Philippines			6.4 (1,330)	7.5 (1,485)
Singapore				5.2 (824)

Source: [4].
Note: Transport cost estimates based on the function 3.2+2.4D between Singapore and other ASEAN countries, where D=1,000 nautical miles, and on 3.6+2.8D between other countries. Figures in parentheses are nautical mile.

TABLE IV

PRODUCTION: INTEGRATED STEEL INDUSTRY
(Plant capacity: 1 million tons per year)

(Million tons)

Country	Pig Iron		Ingots		Billets	
	I	II	I	II	I	II
Indonesia	0.51808	0.81398	0.30330	0.89547	0.273	0.806
Malaysia	—	0.69188	0.26664	0.76115	0.240	0.6851
Philippines	0.15148	1.32761	0.16665	1.46052	0.15	1.3146
Singapore	—	1.45598	—	1.58317	—	1.4319
Thailand	0.25247	1.0	0.27775	1.11867	0.25	1.0
Total	0.92203	5.28945	1.01434	5.81898	0.913	5.2376

Note: Columns headed I and II refer to corresponding excess demand levels. Total cost of the optimal program for level I demand is $96.77 million; and at level II demand, $510.44 million.

country produces at least some of its own demands for all three products. Accordingly, shipping costs decline from about 8 to less than 2 per cent of the total costs.

Note also that while Singapore imported all its requirements for steel under the level I solution, the higher excess demand assumptions result in Singapore becoming the largest producer of all three products. This accords with the assumed relative increases in excess demand, as one can see from Table I.

Some notion of the effect of economies of size can be derived by parametrically varying the cost figures. The results in Table IV use the cost function from Table II pertaining to the smallest capacity—one million tons annual output—for each of the three products. Another solution arises from substituting the second set of cost functions, corresponding to capacity of two million tons per plant. The results appear in Table VI. Level I excess demand for steel billets (913,000 tons

TABLE V
INTRA-REGIONAL SHIPMENTS

(Million tons)

From \ To	Indonesia	Malaysia	Philippines	Singapore	Thailand
Indonesia					
Pig Iron	0.2757	0.14139	—	0.10099	—
Ingots	0.3033	—	—	—	—
Billets	0.273	—	—	—	—
Malaysia					
Pig Iron	—	—	—	—	—
Ingots	—	0.15554	—	0.1111	—
Billets	—	0.14	—	0.10	—
Philippines					
Pig Iron	—	—	0.15148	—	—
Ingots	—	—	0.16665	—	—
Billets	—	—	0.15	—	—
Thailand					
Pig Iron	—	—	—	—	0.25247
Ingots	—	—	—	—	0.27775
Billets	—	—	—	—	0.25

TABLE VI
PRODUCTION: INTEGRATED STEEL INDUSTRY
(Plant capacity: 2 million tons per year)

(Million tons)

Country	Pig Iron		Ingots		Billets	
	I	II	I	II	I	II
Indonesia	—	—	—	0.89547	0.91300	0.91610
Malaysia	—	—	1.01434	0.76115	—	—
Philippines	—	1.32761	—	1.46052	—	1.31460
Singapore	0.92203	1.99000	—	1.58317	—	2.00000
Thailand	—	1.96183	—	1.11867	—	1.00690
Total	0.92203	5.27944	1.01434	5.81898	0.91300	5.23760

Note: Column headings I and II refer to corresponding excess demand assumptions from Table I. Total costs are $103.33 million for excess demand level I, and $498.66 million at level II.

annually region-wide) is now produced by only one plant, and demand for ingots and pig iron is similarly satisfied by a single plant for each product. However, total costs rise from $96.77 million (Table IV) to $103.33 million: the larger plants are less efficient for level I output. By the same token, for the level II assumption of 5.238 million tons regional output, costs actually fall (from $510.44 million to $498.66 million)—again a result of using plants scaled more in line with production levels.

How do the optimal solutions, which imply some interregional trade, compare with national autarky? Since the answers obtained here depend on cost data which differ from country to country only by shipping expenses, and since relatively little of the total regional product is shipped, according to the optimal solutions (from Table V, less than 16 per cent of total tonnage is shipped), one should not be greatly surprised to find that no overwhelming advantage arises from regional integration. With the present data, if one assumes that each country establishes a plant for pig iron, one for ingots and one for billets, the cost of meeting regional demand at level I or level II rises by less than 1 per cent over the cost of the optimal location pattern with trade. However, we conjecture that the use of more realistic manufacturing cost data, which most likely differs substantially between countries, will lead to greater specialization and trade and higher gains therefrom.

In the case of cement, which is treated here as a single-stage undertaking for reasons of both simplicity and lack of more detailed data, substantial economies of scale are available in its production. However, because of its low value-to-weight ratio, cement is not well-suited to large volume, long distance trade. AIS cost estimates refer to no particular location, representing instead costs in any ESCAP country.[6] The survey team did however report actual 1972 unit production costs from Indonesia, Malaysia, the Philippines, and Thailand [8, p. 441]. Hence, for Malaysia and Thailand, we adjust the AIS estimates in proportion to actual costs. Indonesia and the Philippines happen to have identical reported average unit production costs, so we apply the AIS cost estimates for various levels of scale directly. Singapore has no limestone deposits and thus no integrated cement production, although it does import "clinker," the intermediate product leaving the kiln, for further processing and grinding locally. For simplicity in the present illustration, we assume that the Indonesia-Philippines figures apply to Singapore as well. Applying these assumptions to cost figures for each of three levels of scale (0.66, 1.0, and 1.15 million tons per year) gives three points in cost-output space for each country and two linear cost functions. Hence the capacity variable Q_i^s from equation (2) above takes on the values 1.0 and 1.15 for the solutions reported here. The derived cost functions for the plant capacity of 1.0 million tons with shipping costs per unit from i to j denoted by s_{ij} are

$1.359+(11.84+s_{ij})\ q_{ij}$ for Indonesia, Philippines, and Singapore,
$1.176+(11.29+s_{ij})\ q_{ij}$ for Malaysia,
$1.096+(\ 9.79+s_{ij})\ q_{ij}$ for Thailand,

and for 1.15 million tons capacity,

$0.767+(12.43+s_{ij})\ q_{ij}$ for Indonesia, Philippines, and Singapore,
$0.69\ +(10.78+s_{ij})\ q_{ij}$ for Malaysia,
$0.69\ +(10.20+s_{ij})\ q_{ij}$ for Thailand.

Excess demand figures are taken as the difference between AIS projections of total demand in 1985 and production capacity in 1975 of each country [8, pp. 425–27]. Transportation costs are estimated by distributing the current cement

[6] See [8, p. 438]. The AIS data used here refer to so-called "dry process" Portland cement, considered more efficient if moisture content of quarried raw materials is not too high, especially in light of considerable savings in heat consumption.

TABLE VII

PRODUCTION AND SHIPMENT: CEMENT

(Million tons per year)

Country	Total Production	Shipped to				
		Indonesia	Malaysia	Philippines	Singapore	Thailand
I. Plant scale of 1.0 million tons:						
Malaysia	2.87	1.76	0.84	—	0.27	—
Thailand	1.45	—	—	0.19	—	1.26
Total	4.32	1.76	0.84	0.19	0.27	1.26
II. Plant scale of 1.15 million tons:						
Malaysia	2.30	1.19	0.84	—	0.27	—
Thailand	2.02	0.57	—	0.19	—	1.26
Total	4.32	1.76	0.84	0.19	0.27	1.26

TABLE VIII

COSTS OF MEETING EXCESS DEMAND UNDER AUTARKY VS. UNDER TRADE: CEMENT

Country	Excess Demand[a]	Autarky[b]		Trade[c]	
		Number of Plants	Cost[d]	Number of Plants	Cost[d]
Indonesia	1.76	2	23.56	1	—
Malaysia	0.84	1	9.82	2	28.13
Philippines	0.19	1	3.61	—	—
Singapore	0.27	1	4.56	—	—
Thailand	1.26	2	14.53	2	26.69
Total	4.32	7	56.08	4	54.82

[a] In million tons.
[b] Based on plant capacity of 1.0 million tons per year.
[c] Based on plant capacity of 1.15 million tons per year.
[d] In million dollars.

freight rate between Bangkok and Singapore in the proportions implied by the shipping cost data for billet steel.

Results appear in Table VII. The solution for plant scale of 1.0 million tons (I) indicates that Malaysia, with three plants, can supply Indonesia, Singapore and itself, whereas two plants in Thailand will meet the excess demand of both that country and the Philippines. With the scale of 1.15 million tons (II), the pattern of shipping changes only slightly. Malaysia's total output declines by 0.57 million tons and its market in Indonesia is now shared with Thailand.

How do these solutions compare with the costs of each country meeting its own excess demand? Solving the differentiated functions with and without shipping charges yields the figures in the third and fifth column of Table VIII. (We assume the autarkical solution would use the smaller plant size.) Examining the two total cost figures reveals that specialization and trade lowers costs by some 8 per cent region wide.[7] The trade solution requires three fewer plants (four vs.

[7] Trade lowers costs by 6 per cent when plant scale for 1.0 million tons is used for both trade and nontrade situations.

seven). The four high-cost plants required in Indonesia, the Philippines and Singapore for excess demand levels to be met autarkically are offset by adding only one additional plant in Malaysia.

The present model assumes substantial indivisibilities in scale of plants that are feasible. Therefore, the two extra plants required in the autarky solution imply considerably more excess capacity than in the optimal integrated-production case. Autarkic production involves excess capacity of 2.68 million tons annually, compared to the integration scheme's 0.28 million tons.

Based on presently available data only a brief summary of two additional industries, paper and fertilizer, is given below. The model for paper envisions two final products, newsprint and printing and writing paper, as elements of an integrated paper production operation. Both use pulp as a raw material, though in slightly different forms. Urea fertilizer, on the other hand, uses ammonia as its only raw material of importance in the context of integrated production. Accordingly, this industry appears in a model with only two consecutive stages.

Cost functions in both industries were derived in a manner similar to that for steel as described above.[8] Excess demand levels (Table IX) are again directly from AIS studies [8, pp. 33, 136, 139] and plant capacities assumed represent small to medium size operations.

Optimal solutions for the two groups of industries are shown in Table X. Surprisingly, plant locations are widely distributed among ASEAN countries. In every sub-industry, no country has a monopoly production position: two countries have one plant for each product, e.g., a writing paper plant in the Philippines and Thailand.

Table XI compares the cost of each nation producing to satisfy its own demands for urea fertilizers, with regional production-sharing and trade. The cost saving of regional specialization and trade is considerable. Judging from the total (the last row of Table XI), autarky raises total regional production costs by some 34 per cent for urea and 13 per cent for newsprint and writing paper.

TABLE IX

EXCESS DEMAND ESTIMATES:
UREA FERTILIZER, NEWSPRINT, AND WRITING PAPER

(Million tons)

Country	Urea[a]	Newsprint[b]	Writing Paper[b]
Indonesia	0.4	0.165	0.147
Malaysia	0.15	0.087	0.079
Philippines	0.2	0.103	0.267
Singapore	0	0.055	0.066
Thailand	0.2	0.142	0.152
Total	0.95	0.552	0.711

[a] Projected excess demand for nitrogen fertilizers, 1985 [8, p. 33].
[b] Projected consumption, 1985 [8, pp. 136, 139].

[8] The cost estimates are from AIS [8, pp. 79–81, 158]. The costs of producing newsprint and writing paper are based on nonintegrated operations.

TABLE X

PRODUCTION: FERTILIZER AND PAPER INDUSTRIES

(Million tons)

Country	Fertilizer		Paper		
	Ammonia	Urea	Pulp	Writing Paper	Newsprint
Indonesia	0.330	0.590	0.378	—	0.307
Malaysia	—	—	—	—	—
Philippines	0.221	0.360	0.186	0.267	—
Singapore	—	—	—	—	—
Thailand	—	—	—	0.440	0.245
Total	0.551	0.950	0.564	0.707	0.552

Note: Plant capacities: ammonia, 0.33 MTY; urea, 0.59 MTY; pulp, 0.425 MTY; newsprint, 0.5 MTY; and writing paper, 0.5 MTY. One ton of urea requires 0.58 ton of ammonia and one ton of newsprint and of writing paper require, respectively, 0.25 and 0.6 tons of pulp [8, pp. 157–58].

TABLE XI

COSTS OF AUTARKY: UREA FERTILIZER AND PAPER INDUSTRIES

(Million tons)

Country	Urea		Paper	
	Autarky	Trade	Autarky	Trade
Indonesia	14.85	19.25	72.49	81.97
Malaysia	10.24	—	46.09	—
Philippines	11.16	16.02	97.30	83.11
Singapore	—	—	39.18	—
Thailand	11.16	—	71.30	124.34
Total	47.41	35.27	326.36	289.42

For urea, autarky requires two more plants (one each for Malaysia and Thailand) than the optimal trade solution, and leaves excess capacity at 66 per cent instead of 19 per cent (assuming indivisible plants with capacities of 0.33 and 0.59 million tons per year for ammonia and urea, respectively). Similarly, in the case of the paper industry, regional cooperation and trade would require fewer plants and induce a fuller capacity utilization than with autarky.

IV. CONCLUSION

Our model applies to the problem of regional industrial complementation a criterion of efficiency determined by the lowest production cost point. A number of instructive implications can be drawn from the results. First, in comparison with the autarkical solution where national import substitution programs seek to provide for individual country demand, a significant portion of production costs under regional distribution could be saved. Second, industrial projects seem evenly distributed among the five nations such that no one country would have a monopoly position. Our results, though involving only four industries, suggest that equitable dispensation of plants may not be the insurmountable task it seems using the efficiency consideration; that is, the achievement of efficiency and an equitable distribution do not appear mutually exclusive. Third, the number of plants is substantially reduced by the regional production and trade arrangement. Accordingly, reduction in the initial capital costs of equipment and plant construction can be notable.[9] Finally, regional complementation, whether achieved as the natural result of markets in response to lower trade barriers or through agreed specialization, can result in a fuller utilization of plant capacity compared to the individual country solution.

Our analysis, as mentioned, is designed to draw qualitative implications from the model, rather than presenting concrete case studies.

In no way is this paper a substitute for feasibility and cost benefit studies of industries. Furthermore, the lack of available date (for example, differentiated production costs are used in only one industry and even there, they represent the crudest of estimates) has required several broad assumptions. The model itself assumes substantial indivisibilities in the scale of plants that can be built. Finally, the implications of certain assumption must be carefully assessed, e.g., the degree of protection needed to launch and nurture the regional package.

9 U.N. report on ASEAN economic cooperation [6, p. 121] stresses the significance of this saving.

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