PLANNING THE LAYOUT OF A SHOPPING CENTRE

D.C. PAGE

-Senior Lecturer Department of Machanical Engineering, University of Stellenbosch —

INTRODUCTION

In this paper the development of a layout for a shopping centre on a given site in Stellenbosch is discussed. Specific attention is given to the input used to define the affinity between shops, the objective function used to measure the efficiency of layouts for purposes of comparison, and the computor assisted procedure followed in developing the layout. The paper is a followup of an article by the same author in the April 1979 issue of this journal on the Industrial Engineering approach to layout planning.

THE PROBLEM

The site of the planned shopping centre is situated between Bird- and Andringa street and Merriman avenue and Banhoek road in Stellenbosch as shown in figure 1. An interesting aspect of the site is an old historical church which had to be incorporated into the shopping centre (indicated by the code PP in figure 1). The area for the parking space (RR) and the Post Office (SS) were also treated as fixed. A list of the 36 shops that had to be located, as well as their specified floor areas is given in table 1.

Regarding businesses on adjecant plots there are garages on the corner of both Merriman- and Bird-, and Merriman- and Andringa streets facing the shopping centre. A third garage is situated across Merriman avenue more or less in the centre of the block directly opposite the shopping centre. The heavy preponderance of garages results in a situation where practically all sidewalk shops must of necessity face the garage. In consequence, the influence of all busunesses facing the proposed complex had been ignored in this analysis.

The information concerning the site (existing facilities, area zoned for parking space, Post Office, etc.) and the type and sizes of shops to be located in the shopping centre was supplied by Prof. D. Page, chairman of the Department of Town and Regional Planning of the University of Stellenbosch.

THE INPUT USED

A so-called *relationship chart* shown in table 1 was used as input to indicate the affinity between the different shops (the extent to which it would be desirable to have each pair of shops adjecent). The following symbols were used:

- **I** - Important for the particular pair of shops to be adjacent.
- **O** - This pair of shops is Ordinarily situated close to each other.
- **U** - It is Unimportant whether this pair of shops is adjacent.
- **X** - This pair of shops repel each other and they should *not* be adjacent.

The entry right at the top of the chart indicates for example that the supermarket and department stores should not be adjacent (**X**). Neither should the supermarket and the bank be adjacent (**X**), but it is unimportant (**U**) if the cafe is adjacent to the supermarket. As another example the bookshop and the haberdashery are usually close to each other (**O**), whereas the bookshop and the motor spares shop repel each other (**X**).

The chart was compiled mainly on the basis of a student survey. Ten students (5 male and 5 female) each compiled an individual chart, after which their charts were assembled into a single relationship chart by more or less averaging the results. This chart was then amended after careful reasoning to eliminate discrepancies and inconsistencies and also after comparison with a similar chart independently compiled by the author. It should be mentioned that the compilation of a relationship chart of this magnitude (39 facilities, 780 entries) is a laborious and difficult task. Hopefully the chart might be of value as a reference to planners in the solution of similar problems.

Some discussion concerning the principles involved in the compilation of these type of subjective judgment charts might be of value. One approach is to use the so-called Laplace criterion utilised in decision theory. Laplace, a French mathematician, stated that under complete uncertainty each state of nature should logically be considered "equiprobable" or equally likely. The rationale underlying this criterion is that if the decision maker does not feel comfortable with *these equal probabilities* this implies that he would feel more comfortable with *some other probabilities* in which case the original state of "complete uncertainty" ceases to apply. Applied to the compilation of a relationship chart the Laplace criterion can be interpreted in two ways. One could reason that all closeness ratings should be **U** (Unimportant) and if the compiler of the chart feels uncomfortable with an **U** in a particular case for a specific reason he should amend the rating to his preference. Secondly the chart in figure 1 (or any existing chart) is a starting point which the player can amend when he can logically motivate the alteration.

THE OBJECTIVE FUNCTION

For an analytical approach to the layout problem it is necessary to define a quantitative measure of efficiency which can be calculated for a given layout. The value of this objective function can then be compared for different proposed layouts to assist in the selection and development of an acceptable solution. In the case of a relationship chart type of input specification one of two basic quantitative measures of efficiency can be used. In both cases a numerical value is attached to the different closeness rating codes, say **I** = 4, **O** = 1, **U** = O and **X** = - 4 for the shopping centre examples. The numerical value of the objective function can then be calculated as follows.

Firstly the closeness rating for each pair of facilities can be multiplied by the distance between the facilities and summed for all pairs to form a distance weighted total closeness rating for a particular layout. Refer to equation 1 for the mathematical expression of this objective function. This total closeness rating is in fact the equivalent to total materials handling cost per time unit for a given layout. The number of loads moving between all pairs of facilities are put equal to unity and the materials handling cost per unit load per unit distance between each pair of facilities taken as the numerical value of the closeness rating for that pair.

In the case of the shopping centre the author felt that it was not really logical or necessary to weigh the closeness ratings in pro-

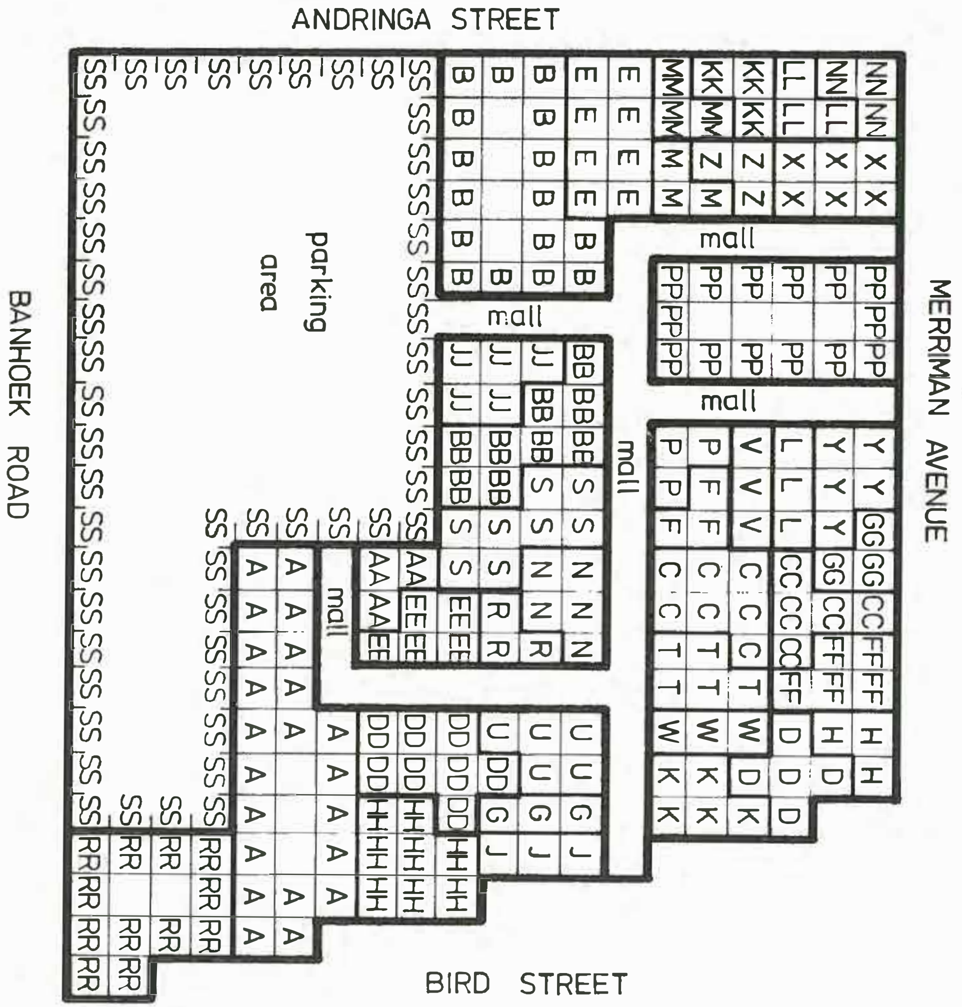
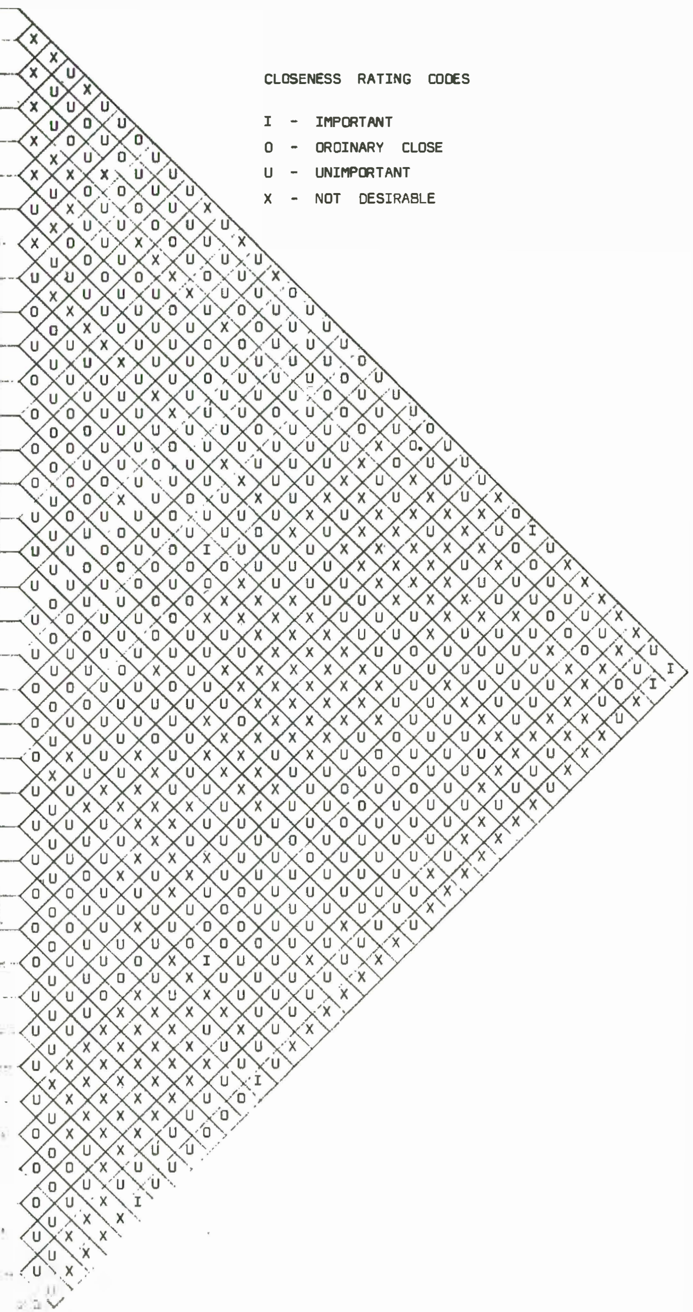


FIG. 1 Proposed Layout for Shopping Centre.

TABLE 1 - RELATIONSHIP CHART FOR SHOPPING CENTRE

		SPECIFIED SIZES (6 x 6 m^2 MODULES)
A	SUPERMARKET	20
B	DEPARTMENT STORE	16
C	BANK	6
D	CAFE	4
E	RESTAURANT	6
F	COFFEE BAR	2
G	DELICATESSEN	2
H	GREENGROCER	2
J	SHOE SHOP	2
K	OUTFITTER	4
L	BOUTIQUE	2
M	JEWELLER AND WATCHMAKER	2
N	GLASSWARE	4
P	GIFT SHOP	2
R	FLORIST	2
S	ANTIQUE DEALER	6
T	BOOKSHOP	4
U	SPORTS SHOP	4
V	HABERDASHERY	2
W	RECORD BAR	2
X	PHARMACY	4
Y	HAIRDRESSER	4
Z	TRAVELLING REQUISITES	2
AA	PET SHOP	2
BB	FURNITURE STORE	6
CC	BYCICLE SHOP	4
DD	HARDWARE STORE	8
EE	GARDEN EQUIPMENT	4
FF	MOTOR SPARES	4
GG	DRY CLEANERS	2
HH	BUTCHER	6
JJ	ELECTRICAL EQUIPMENT	4
KK	PHOTOGRAPHER	2
LL	TRAVEL BUREAU	2
MM	OPTICIAN	2
NN	BUILDING SOCIETY	2
PP	CHURCH	18
RR	POST OFFICE	14
SS	PARKING AREA	136



CLOSENESS RATING CODES

I - IMPORTANT

O - ORDINARY CLOSE

U - UNIMPORTANT

X - NOT DESIRABLE

portion of the distance between facilities. The distance between shops should not be taken into acount at all and each pair of shops should simply be classified as adjacent or not adjacent and the closeness ratings for only the adjacent shops in a given layout summed to form a quantitative measure of efficiency : refer to equation 2. Only the shops with an adjoining wall facing the same sidewalk or mall, or those facing each other across a mall are judged to be adjacent, and added into the objective function. If two shops are not adjacent, but removed from each other with say a few other shops (or the Church for example) in between, their closeness rating is of no importance and is neglected.

Minimise $$C = \sum_{i=1}^{n} \sum_{u=1}^{n} c_{ij} a_{ij}, \quad i \neq j \qquad 1$$

where c_{ij} = closeness rating for facilities i and j

a_{ij} = distance between facilities i and j

n = number of facilities

Minimise $$C = \sum_{i=1}^{n} \sum_{j=1}^{n} k_{ij} c_{ij}, \quad 1 \neq j \qquad 2$$

where k_{ij} (0,1); k_{ij} = 1 if shops i and j are adjacent and k_{ij} = 0 otherwise

THE SOLUTION

The final layout arrived at is shown in figure 1 as a matrix of characters representing the different shops, the idea being that architectural drawings can be constructed with the matrix layout as a guideline. The computor programs used to assist the analyst in developing the layout use the same notation.

Sizes of facilities are approximately specified by the number of characters used to represent it. In this case each character represents a 6 x 6 = 36 m^2 square. Note that all the shops in the proposed layout are from 1/4 to 1/3 oversize in comparison to the sizes specified by prof. Page and listed in table 1. The mall on the other hand is too narrow; 6 m in comparison to the minimum of 8 m usually accepted. When making the final drawings this discrepancy, which is mainly caused by the limitations imposed by the matrix notation using equal cells, can be rectified.

The calculation of the value of the objective function according to equation 2 for the proposed layout is shown in table 2. Note that shops facing each other directly or diagonally across a mall were also taken as adjacent. This convention can naturally be changed to suit the analyst.

The layout shown was developed by manipulating various layouts generated by the two computor layout programs. The CRAFT program (Computerized Relative Allocation of Facilities Technique), developed by Buffa and Armour, performed remarkably well even though it uses the distance weighted objective function expressed in equation 1, which was in fact *not* used for the final comparison of alternative solutions. This program starts from an initial solution specified by the user. All feasible exchanges of two and/or three facilities are then evaluated and the most promising exchange is implemented, after which the "new" layout is then again scanned for improvement possibilities from all possible exchanges, and the procedure repeated until the program terminates when no profitable exchange can be detected.

The second program, ALDEP (Automated Layout Design Program), developed by Seehof and Evans, which does use the correct objective function, equation 2, gave disappointing results. This program does not start from an initial solution, but selects the first facility to be located at random and locates it in the upper left hand corner of the layout. It then finds the facility with the highest closeness rating to the facility just located, locates it next to this facility and repeats the procedure for all the remaining facilities. Ties between candidates for placement are broken through random selection and it is possible to use the program as a completely random layout generator by specifying the appropriate parameter. The program calculates the value of the objective function for the layout and prints the layout out if this value exceeds a cutoff point specified by the user. It generates any number of layouts specified by the user. In the case of the shopping centre 2 000 layouts were generated and the best two taken for further manual refinement.

The first problem with the ALDEP program is that it generates completely impossible layouts. In the "best" ALDEP layout the supermarket for example straddles the church with one part of the supermarket on one side, and the rest on the other side of the church. The program secondly does not "look sideways" at the facilities already located when placing a new facility, but only considers the closeness rating of the department to be placed with the last facility located. This results in closeness specifications not being satisfied, especially in this case where many shops repel each other with an X closeness rating. The program also was very expensive at R10 to R20 per run (1 000 layouts generated) in comparison with the CRAFT-program with a cost of approximately R1 per run.

In this case both programs also wrongly considered back to back shops to be adjacent (shops with an adjoining back wall but one facing the sidewalk and the other the mall for example). It was hoped that this problem could be overcome in the ALDEP program, which can handle multifloor layouts, by specifying the part of the site facing the sidewalk on a different floor from that facing the mall. Unfortunately this was not successful due to limitations of the program. The program considers floors to be completely independent and for example does not accept facilities on two different floors, but next to the same stairwell (the position of which can also be specified) as adjacent. Furthermore, a considerable number of cells have to be left empty in the layout matrix for the multifloor program facility to function at all (less shop area than total available area have to be specified in the form of "dummy" cells).

One advantage of the computor programs is that they suggest unusual types of possibilities which the analyst might miss. The computor generated layouts also assist the analyst in developing the basic configuration to be used in the final layout.

DISCUSSION

The most difficult part in the solution of the problem was the compilation of the relationship chart table 1. This chart should be of real value as a starting point in the case of a similar shopping centre layout problem. The two different types of objective functions defined in equations 1 and 2 — one weighted and the other not weighted for the distance between facilities — should also be useful when a quantitative measure of efficiency is necessary for an analytic approach to a layout problem. Lastly, the specification of preliminary layouts in matrix form as illustrated in this example is a time saving suggestion. Only the final drawings need to be made to exact scale.

In connection with the solution procedure it should be mentioned that it was not intended to convey a negative impression concerning the usefulness of computor layout programs. It is in fact almost impossible to develop a near optimal layout of this magnitude within a reasonable time with no computor assistance. Computor generated layouts are however very seldom practically employable without manual refinement, but they do

Table 2 — Closeness Ratings for Pairs of Adjacent Shops

Shops	code	value	Shops	code	value	Shops	code	value	Shops	code	value
A(AA)	U	0	E(PP)	X	-4	NT	O	1	XZ	U	0
A(DD)	U	0	FN	U	0	NU	U	0	X(NN)	U	0
A(EE)	U	0	FP	U	0	PS	U	0	X(PP)	U	0
A(HH)	I	4	FS	U	0	PV	O	1	Y(GG)	U	0
A(RR)	U	0	GJ	U	0	P(BB)	U	0	Y(PP)	U	0
A(SS)	I	4	GK	U	0	P(PP)	U	0	Z(PP)	U	0
BE	U	0	GU	U	0	RU	U	0	(AA)(EE)	O	1
B(BB)	O	1	H(FF)	U	0	R(DD)	U	0	(AA)(SS)	U	0
B(JJ)	O	1	JK	O	1	R(EE)	O	1	(BB)(JJ)	O	1
B(PP)	X	-4	J(HH)	U	0	ST	U	0	(BB)(PP)	U	0
B(SS)	I	4	KU	O	1	S(AA)	X	-4	(BB)(SS)	I	4
CF	O	1	KW	O	1	S(BB)	O	1	(CC)(FF)	O	1
CN	U	0	LV	U	0	S(SS)	U	0	(CC)(GG)	U	0
CS	O	1	LY	I	4	TU	U	0	(DD)(EE)	O	1
CT	O	1	L(PP)	U	0	TW	O	1	(JJ)(SS)	I	4
DH	O	1	MZ	O	1	UW	O	1	(KK)(LL)	O	1
DK	U	0	M(PP)	U	0	U(DD)	U	0	(KK)(MM)	O	1
EM	O	1	NR	O	1	U(EE)	U	0	(LL)(NN)	O	1
E(MM)	U	0	NS	O	1	V(PP)	U	0	(RR)(SS)	O	1

Summary:

Closeness rating		Numerical value	Number in layout	Total closenest rating
Important	I	4	6	24
Ordinary close	O	1	27	27
Unimportant	U	0	40	0
Undesirable	X	-4	3	-12
				39

serve as a valuable starting point for the analyst to work from.

ALDEP and CRAFT are the two most useful programs for the type of problem considered in this paper where the shape of the floorplan is fixed. A variety of other programs are also available. The PLANET and CORELAP programs are for example used when no basic floorplan exist in which the facilities have to be fitted and the building or floorplan can be constructed to suit the layout.

The author is convinced that knowledge of the analytical approach employed by the Industrial Engineer to layout problems as illustrated in this paper and its predecessor in the April 1979 issue of this Journal should be of value to the Town and City Planner. And finally the enthusiastic reader is invited to improve the proposed layout to exceed the total closeness rating of 39 calculated in table 2.

REFERENCES

Francis, R.L., White, J.A.: *Facility Layout and Location,* Prentice-Hall, 1974.

Page, D.C.: "Die Bedryfsingenieursbenadering tot Uitlegbeplanningsprobleme", *Journal for Regional Planning,* April 1979.

Page, D.C.: "Lower handling and energy cost by layout planning", *South African Materials Handling News,* January 1980.

Tompkins, J.A., Moore, J.M.: *Computor Aided Layout: A User's Guide,* AIIE, Atlanta, 1978.