Linear programming from a management point of view : a survey, Netherlands, 1976

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Received July 1977
Revised October 1977

Linear programming is deemed to be the economically most valuable single device employed in operational research. The aim of this survey is to assess the usefulness of linear programming for the management of organizations. Expressing usefulness in money terms means assessing hard-to-grasp total costs and still-harder-to-grasp total benefits. Most attention is therefore paid to the first step: assessing the use of linear programming. A complete stock-taking is envisaged of all LP applications in the Netherlands, up to 1977. Applications are classified by industrial or government sectors and by type of problem. Questions have been asked about the various phases of an LP application:

– original data collection and updating (who does what?),
– modelling (characteristics of the models and the modelling activity),
– computing (hardware, and software: special options and other techniques of mathematical programming used),
– implementation of results (interface with the end users).

1. Introduction

Linear Programming is one of the show cases of Operations Research. LP has indeed to some extent determined the image of OR. In most textbooks on OR one finds statements similar to the following one by Wagner [9, p. 33]:

"Unquestionably, linear optimization models are among the most commercially successful applications of operations research; in fact, there is considerable evidence that they rank highest in economic impact".

This is precisely what a manager would like to know: how useful is LP for me and what can be gained from it? We hope to come some way towards answering this question in the present survey. It has been conducted in the Netherlands, October–December 1976, and is mainly concerned with questions regarding by whom and for what LP is used. As might be expected, findings about economic gains are scarce, however.

Consider the Netherlands as a sample from the Western developed countries. It is a 14-million people country in the Rhine delta traditionally involved in trade and farming (especially dairy). Since World War II, it rapidly industrialized. About 5 per cent of the professional population still works in the primary sector (agriculture); of the employed, about 40% is in the secondary sector (manufacturing industry), 30% in the tertiary sector (commercial services), and 25% in the quartary sector (non-profit organizations and government). National income in 1975 was 185 billion guilders, i.e. 13.5 thousand guilders per capita (1 guilder ≈ 1 Deutschmark ≈ $ 0.40). The total number of firms and other organizations is not so meaningful since the size distribution is very skew. But as the use of LP increases more than proportionately with the size of an organization, it should be mentioned that the Netherlands house a few very large firms. In *Fortune's* August 1976 list of the fifty largest industrial companies in the world, Royal Dutch/Shell Group ranks 3rd, Unilever 10th, and Philips' Gloeilampenfabrieken 16th. In the agricultural sector, the Large Scale Farm of the IJsselmeerpolders Development Authority with its 22,000 hectares is ten times as large as the second-largest agricultural organization in Western Europe.

The survey aimed at a complete stock-taking of LP applications in the Netherlands. Completeness was pursued by a multiple approach. (1) The assistance of computer manufacturers was sought to trace LP users among their clients; this assistance, we gratefully acknowledge, was given by 8 manufacturers. (2) University computing centers were approached similarly. (3) Finally, firms were approached directly on the basis of indicators of LP use such as

– type of industry (e.g., process industry),
– size (sales, personnel),
– presence of specialized department (e.g., OR department),
– hardware/software availability.

Paper presented at XXIIIth International Meeting of The Institute of Management Sciences, Athens, July 25–27, 1977.

European Journal of Operational Research 2 (1978) 223–231.

The Computer Address Guide [1], the COSSO Vademecum [2], and the *Financiële Dagblad* survey of Dutch firms [4] served as checklists. In total, 63 organizations using LP were identified.

Special attention was paid to the nonresponse problem, which is particularly severe in written inquiries. Three measures taken may be mentioned. (1) A pre-survey was conducted consisting of interviews lasting $1\frac{1}{2}$–4 hours among 10 organizations, in order to test and improve the written questionnaire. (2) In most cases, before mailing the questionnaire, a telephone call was made to verify whether LP was used and identify a person to whom the questionnaire could be addressed. (3) In case of nonresponse, after one or two months a reminder was sent. In this way, a response of 86 per cent was achieved.

A survey aiming at a complete enumeration can only be biased towards an *underestimation* of the true use of LP because, barring window-dressing or cheating, an application can be mistakenly omitted from, but can never be mistakenly included in, the survey. On the other hand, conclusions based on *sample* surveys may be biased towards an *overestimation* of the true use of LP, if the more active firms in the field are overrepresented in the sample. Besides, if the response is low, all conclusions based on the sample are very uncertain. This may be the case with some other surveys in this area. The Deutsche Gesellschaft für Operations Research LP survey [7, p.8] was based on 44 firms responding out of 700 (response 6 per cent). Three American surveys [8,3,5] had responses of 23, 18, and 35 per cent, respectively.

We will now briefly discuss the results, relying mainly on the tables. A more detailed account is given (in Dutch) in the unpublished but freely available Master's thesis of the first author [6].

2. Results

Number of organizations (Table 1)

Out of 98 firms questioned, 84 reacted, 63 used LP, and 56 of the latter returned completed questionnaires. These 56 organizations were subdivided into Agriculture (8); Food and fodder processing industries (14); Manufacturing industries, which only consisted of Oil refineries, Chemical industries, and Metal work industries (12); Services and utilities (14); and Universities (8). [1]

[1] Abbreviated in the tables to: Agric., Foods, Oil, etc., Serv., Univ., respectively.

Table 1
Number of organizations

	Number	%
Questionnaires sent	118	
Different organizations	98	100
Response	84	86
LP applied	63	64
Completed questionnaires	56	57
– Agriculture [a]	8	
– Foods [b]	14	
– Oil, etc. [c]	12	
– Services [d]	14	
– Universities [e]	8	

[a] Including Construction (1), Land use planning (1).
[b] Dairy products (1), Sugar (2), Flour and bread (2), Meat (1), Other food processing (2), Cattle-food industry (6).
[c] Oil refineries (3), Chemical industries (5), Metal work industries (4); all other industries yielded zero questionnaires.
[d] Management consultancy bureaus (4), Financial institutions (1), Transportation (2), Energy (1), Other utilities and local government (6).
[e] Universities, which may apply LP as an end in itself rather than as a means, were not counted in the questions regarding firms using LP (thus leaving a total of 48 firms), but the LP applications contributed by them were included (under Services) in the questions regarding specific LP models. On the other hand, Consultancy bureaus were counted (under Services) in the questions regarding firms using LP, but the LP applications contributed by them were included in the sectors for which the specific LP models had been developed.

LP is applied in all four economic sectors: the primary (agriculture), the secondary (manufacturing), tertiary (services), and quartary (nonprofit institutions). However, in the secondary sector it is mainly applied in the process industry (flow shops). Firms producing compound products (job shops, assembly industries) are conspicuously lacking. It seems that LP applications "jump" from the primary sector and the process industry to the tertiary and quartary sectors.

When was LP started? (Table 2)

In each of the last four 5-year periods, the number of new firms starting LP increased. 52% of the firms started LP in the last five years only. (Especially Foods and Services are late-comers.) This may indicate that the "market" for LP applications is as yet far from saturated.

It should be remarked, however, that this survey is one of current LP users. It was not possible to

Table 2
When was LP started?

Year started	Agric.	Foods	Oil, etc.	Serv.	Total	%
⩽ 1960	1		1	1	3	5
1961–1965	2	3	3	1	9	19
1966–1970	3	2	4	2	11	23
⩾ 1971	2	9	4	10	25	52
Total	8	14	12	14	48	100

trace former LP users that have dropped LP. Table 2 tends, therefore, to underestimate LP application in the past, and what seems like growth may be in part just a "changing of the guard".

Number of LP models per organization (Table 3)

The total number of LP applications claimed by the 48 firms to have been developed since they started using LP is 247, an average of 5 models per firm. However, 38% of the firms (especially in the Food and fodder processing industry) operated only one model; on the other hand, 10% operated more than 10 models. The extremes were two firms having together developed 25 + 57 = 82 models or one third of the total.

The figures giving numbers of models must be qualified as rather soft, since one firm may call so-many models what another firm may call one model with so-many variants.

Table 3
Organizations classified by number of LP models

LP models	Agric.	Foods	Oil, etc.	Serv.	Total	%
1	2	9	2	5	18	38
2–5	5	3	4	7	19	40
6–10	1	1	3	1	6	12
⩾ 11		1	3	1	5	10
Total	8	14	12	14	48	100

Taking the total number of LP models stated, and even doubling it to account for a possible underestimation inherent in the survey, we arrive at about 500 LP models for the Netherlands. This is about 35 models per million inhabitants, or 3 models per billion guilders of 1975 national income. If this seems low, then perhaps expectations of the impact and success of LP have been too high.

Number of models by type of problem (Table 4)

Table 4 shows that there are many models in the mixing and blending area (29%), followed by production planning (26%), and location and investment problems (20%). Most of the problems are of a physical nature. Financial models of corporate planning and costing are still a minority (7%). A pure transportation problem allowing the transportation algorithm to be used occurred only once.

Which department mainly applies LP?

In those firms where one department was mainly

Table 4
Number of LP models by type of problem

Type of problem	Agric.	Foods	Oil, etc.	Serv.	Total	%	Detailed [c]
Mixing and blending	1	56	11	4	72	29	16
Production planning [a]	5	20	27	12	64	26	20
Distribution [b]	3	3	7	6	19	8	10
Location and investment	9	5	23	13	50	20	17
Corp. planning and costing	7	1	3	6	17	7	12
Unspecified			25		25	10	
Total	25	85	96	41	247	100	
Detailed [c]	12	20	24	19			75

[a] Including (in total) sequencing problems (2), cutting problems (2).
[b] In only one instance use was made of the transportation algorithm.
[c] The detailed models were contributed by the firms in response to the request to provide one or two representative examples of their LP applications. Per LP model, a set of specific questions was asked which are dealt with below (Tables 10–15). In addition to the 75 models supplied by the firms, 12 models supplied by the universities were included, raising the total number surveyed to 87 (see also footnote e of Table 1). Since not all questions regarding models were answered for all models, the totals of Tables 10–15 add up to less than 87.

responsible for LP, this was:

– OR department	16 X
– planning department	8 X
– financial/administrative department	1 X
– other departments	10 X.

Division of labour between staff group and end user

The end user of LP is defined as the person who needs the results of the LP model to perform his normal duties.

The division of labour between the staff group, applying LP, and the end user, needing the results, was as follows:

	Staff group (%)	*End user* (%)	*Both* (%)	*Neither* (%)	*Total* (%)
Data collection	11	57	32	–	100
Model building	64	18	18	–	100
Model solving	81	12	7	–	100
Implementation	33	13	36	18	100
Software development	76	7	–	17	100

It seems that in 18% of the firms results of LP were not put to use. Only data collection was mainly carried out by the end user; the other phases in the application (even implementation) were mostly performed by the staff group. When asked about the *ideal* division of labour with respect to model building and maintenance, and data collection and updating, the majority of the firms considered it desirable that these activities be performed by the end user; in about half of these firms, however, these activities were in reality performed by the staff group.

LP users by level of education (Table 5)

A user of LP is defined as a person who applies LP. LP users mostly have a high level of education, 45% being university graduates. This percentage is lower in the Food and fodder processing industries, where many simple blending problems require less professional know-how.

LP users by source of LP know-how (Table 6)

The high degree of education, on the average, of LP users does not mean that they learned the technique at school. Only 30% did so. The majority in all sectors (except Services) learned about LP in an internal course provided by the organization itself.

Combined with the fact that 52% of the firms started LP only in the last five years, this result suggests that here is an area neglected by the educational institutions.

External consultancy (Table 7)

In view of the fact that 70% of the LP users had to learn about LP *after* their school education, it is not surprising that 85% of the firms had recourse to external consultancy. The order in which external consultants were resorted to is: computer manufacturer (38%), university (26%), other LP users (20%), and consultancy bureau (16%). Consultancy related to LP modelling as well as to software problems.

Facilities used for LP computations (Table 8)

The majority of the firms (46%) use their own computer center. Service bureaus are seldom applied to (9%), in contrast to manufacturers' computer centers (29%). For historical reasons, Agriculture has special ties with universities.

Software used (Table 9)

38% of the firms use IBM software, 21% employ home-made software (including software houses operating their own packages), and 15% the software package developed by the Mathematical Centre in Amsterdam.

Table 5
LP users by level of education

Level of education	Agric.	Foods	Oil, etc.	Serv.	Total	%
University	11	13	30	30	84	45
Higher professional	8	23	25	6	62	34
Medium professional	6	12	10	10	38	21
Total	25	48	65	46	184	100

Table 6
LP users by source of LP know-how

Source	Agric.	Foods	Oil, etc.	Serv.	Total	%
School/university	6	8	17	24	55	3(
External course	4	8	7	13	32	1
Internal course	10	23	22	5	60	3
Self-taught	5	6	9	2	22	1
Unknown		3	10	2	15	
Total	25	48	65	46	184	10

Table 7
External consultancy

Firms/Consultants/Problems	Agric.	Foods	Oil, etc.	Serv.	Total	%
Firms						
did consult	8	13	9	11	41	85
did not consult		1	3	3	7	15
Total	8	14	12	14	48	100
Consultants						
Computer manufacturer	2	11	7	3	23	38
Consultancy bureau	3	1	3	3	10	16
University	5	4	1	6	16	26
Other LP users	5	2	2	3	12	20
Total	15	18	13	15	61	100
Problems						
LP modelling	6	10	4	6	26	34
Software choice and use	4	7	8	7	26	34
Software efficiency	3	5	4	3	15	20
Software development	2	4	2	1	9	12
Total	15	26	18	17	76	100

Table 8
Facilities used for LP computations

Facility	Agric.	Foods	Oil, etc.	Serv.	Total [a]	%
User's computer center	2	8	8	9	27	46
Manufacturer's computer center		7	4	6	17	29
Service bureau	2	1		2	5	9
University computer center	5	1		2	8	14
Elsewhere			1		1	2
Total [a]	9	17	13	19	58	100

[a] Some organizations use more than one facility.

Table 9
Software used

Software [a]	Agric.	Foods	Oil, etc.	Serv.	Total	%
IBM		7	9	2	18	38
CDC	3			1	4	8
Univac		1	1	1	3	6
Honeywell-Bull		3			3	6
Burroughs			1		1	2
Universities [b]	5	1		2	8	17
Home-made		2	1	7 [c]	10	21
Unknown				1	1	2
Total	8	14	12	14	48	100

[a] Together with computer manufacturer's software the hardware was always used as well.
[b] Including the Mathematical Centre package (7 times).
[c] Includes software packages built and operated by software houses.

Hardware used

Those firms that use computer manufacturer's software, also apply the manufacturer's hardware. The 18 firms using home-made and university-made software, use hardware from 9 different computer manufacturers.

Only 9 firms operate a large LP package on a large computer in their own computing center (7 of which use IBM's MPS-X, 1 CDC's APEX-III, and 1 Burroughs's TEMPO). But these 9 firms together have developed 134 models, which is more than half of all models found in the Netherlands.

Other mathematical programming techniques

Nonlinear programming was reported to be used by 12 firms (25%), dynamic programming by 8 firms (17%). 21 firms reported not to use any other OR

Table 10
Frequency of LP model use

Frequency (f)	Agric.	Foods	Oil, etc.	Serv.	Total	%
$f \geq$ once/month	4	15	11	4	34	45
once/month $>$ $f \geq$ once/year	4	1	9	8	22	29
$f <$ once/year [a]	5	2	5	8	20	26
Total	13	18	25	20	76	100

[a] Includes one-shot applications.

Table 11
Planning horizon of LP models

Panning horizon (h)	Agric.	Foods	Oil, etc.	Serv.	Total	%
$h \leq 1$ month		8	3	2	13	21
1 month $< h \leq$ 1 year	5	6	14	2	27	44
$h >$ 1 year	5		4	13	22	35
Total	10	14	21	17	62	100

Table 12
Number of constraints in LP models

Number of constraints	Agric.	Foods	Oil, etc.	Serv.	Total	%
≤ 50	3	5	3	3	14	21
51 – 150	3	3	5	5	16	24
151 – 500	4	3	9	7	23	34
> 500		4	6	4	14	21
Total	10	15	23	19	67	100

techniques besides LP at all; 13 of these LP-only users were Food and fodder processing industries.

Frequency of LP model use (Table 10)

The remainder of the results (Tables 10–15) relate to the 87 models contributed by the organizations as representative examples of their LP applications.

The frequency of LP model use in Foods and Oil, etc. is mostly at least once a month, whereas Agriculture and Services run their models mostly less than once a year (this includes the study models used only once).

Planning horizon of LP models (Table 11)

Planning horizons are negatively correlated with frequency of use. Models in Foods have the shortest horizon (mostly up to one month), those in Oil, etc. mostly have a horizon between one month and one year, and in Agriculture and Services over one year.

In all, 65% of the models have a horizon up to one year, which confirms the idea that LP is still mainly applied to short term problems (see also Table 4).

Number of constraints in LP models (Table 12)

A large part (45%) of the models are small – up to 150 constraints; 34% are medium – between 150 and 500 constraints; and only 21% are large – above 500 constraints. Models of various sizes are fairly evenly spread over sectors.

Variables and density as related to constraints (Tables 13 and 14)

The number of variables in the models is positively correlated with the number of constraints. In Table 13, the largest elements in columns and rows are on the main diagonal. The reverse is true of density (i.e. the percentage of nonzero elements in the A-ma-

Table 13
Constraints and variables

Number of constraints	Number of variables				
	≤ 100	101–300	301–1000	> 1000	Total
≤ 50	13	1			14
51 – 150	2	9	3	2	16
151 – 500		8	12	3	23
> 500			4	10	14
Total	15	18	19	15	67

Table 14
Constraints and density

Number of constraints	Density (d)				
	$d \leq 1\%$	$1 < d \leq 3\%$	$3 < d \leq 10\%$	$d > 10\%$	Total
≤ 50			1	8	9
51 – 150	1	3	8	1	13
151 – 500	3	11	6	2	22
> 500	12				12
Total	16	14	15	11	56

trix): in Table 14 the other diagonal dominates.

Scatter diagrams are given in Fig. 1 and 2. The regression line of number of variables (v) on number of constraints (c) is

$$\log v = 0.29 + 0.98 \times \log c$$

(the correlation coefficient is 0.85).

The regression line of density (d) on number of constraints is

$$\log d = 2.7 - 1.04 \times \log c$$

(the correlation coefficient is 0.66).

Options used (Table 15)

Options used were reported for 73 models. For those options which are sometimes used by default, results are not very reliable since they may or may not have been included in the answers. The major nondefault options reported are the initial starting base feature (37%), the mixed integer programming feature (29%), and parametric programming (22%). Other options like generalized upper bounds (12%), separable programming (3%) and decomposition (3%) are seldom used.

Input and output

For 52% of the models use was made of a matrix generator and report writer which were mostly home-made.

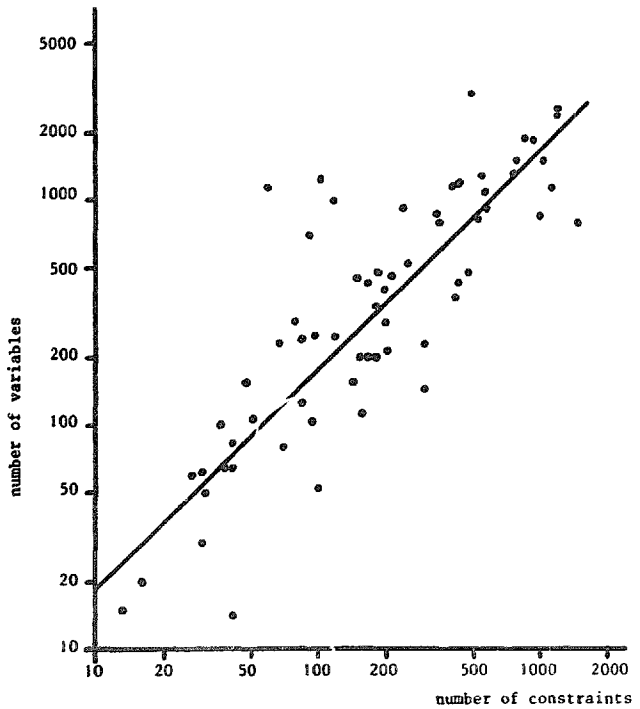

Fig. 1. Constraints and variables in LP models.

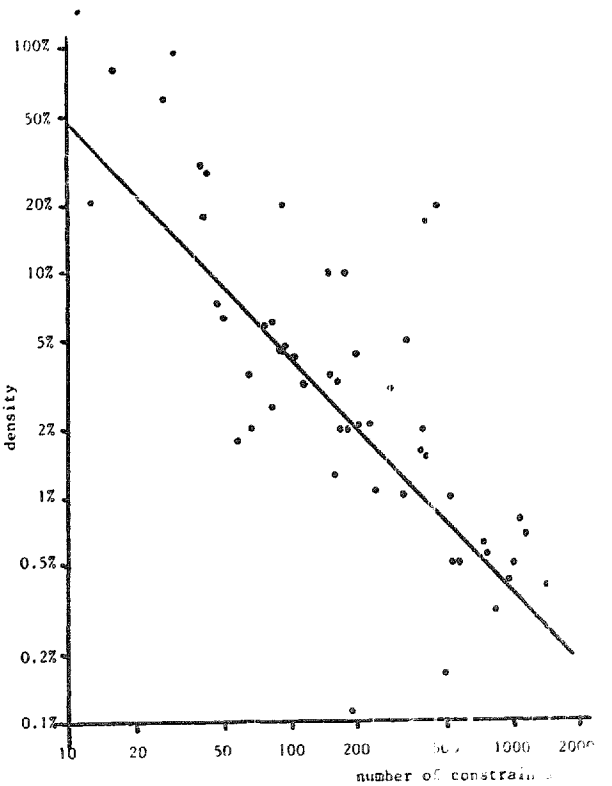

Fig. 2. Constraints and density in LP models.

Table 15
Options used

Options	Agric.	Foods	Oil, etc.	Serv.	Total	% [a]
Reinversion	5	10	13	8	36	49
Initial basis	2	8	9	8	27	37
Mixed integer programming	7	1	4	9	21	29
Parametric programming	4	4	4	4	16	22
Scaling	2	8	4	2	16	22
Generalized upper bounds	1	1	3	4	9	12
Reduce	2	2	2	1	7	10
Separable programming			1	1	2	3
Decomposition		1		1	2	3

[a] Total number of responses was 73.

Economic gains

For 73% of the models it was stated that economic gains had been made; however, for 47% the gains could not be quantified. For those 26% whose gains were quantified the total gains were 15 million guilders per year which is about one guilder per capita in the Netherlands. We hope that this is only a small fraction of the true benefits achieved from linear programming.

3. Summary and conclusions

– A survey was conducted in October–December 1976 trying to enumerate Linear Programming applications in the Netherlands.

– Although response was 86%, only 43 firms were included in the survey. They were distributed over all four economic sectors, viz. the primary (Agriculture), secondary (Manufacturing), tertiary (Services), and quartary (Non-profit institutions). Within the secondary sector, process industries (food processing, oil refineries, chemical firms) were well represented but assembly industries were almost absent.

– The 48 firms stated to have developed 247 models – 38% of the firms had only one model and two large firms accounted for 82 models. Roughly, 35 LP models per million inhabitants may have been developed, or 3 models per billion guilders of 1975 national income.

– 52% of the firms had started using LP only after 1970. It is expected that the number of LP users will continue to grow.

– LP was mostly an (OR) staff group activity performed by academically trained staff. Yet, 70% of LP users had learned the LP technique after they had left school. Extensive use was made of external consultancy (85% of the firms).

– Software and hardware were used from various sources. Only 9 firms employed a large LP package on a large self-owned computer but these firms accounted for one half of all models developed.

– Detailed descriptions were given of 87 models representative of the LP applications of the organizations.

– Frequency of model use was negatively correlated with planning horizon of the models. The majority of models is run at least once a month with a planning horizon of up to one year. The majority of the models still relate to short-run problems of a physical nature.

– The number of restrictions is positively correlated with the number of variables and negatively with the percentage of nonzero elements in the A-matrix. The quantitative relations were assessed.

– Specific options used regularly are (a) starting with an initial basis, (b) mixed integer programming, and (c) parametric programming. Other options are seldom used. Together with the restricted size of many models (45% have less than 150 constraints), this leads to the conclusion that there is still a sizeable demand for simple, unadorned LP software based on the 30-year old, straightforward simplex algorithm.

– In 52% of the cases use was made of a matrix generator and report writer. These were mostly tailor-made.

– Economic gains could hardly be assessed – the fact that LP *is* used is a more reliable indication for its usefulness than many a cost-benefit analysis may provide.

– Other questions have been asked, e.g. on num-

ber of iterations, CPU-time, and running costs, but these could hardly be evaluated because of different characteristics of models and options used (e.g., starting with an initial basis). It will be tried to bring such aspects on a comparable basis in an intended user's test of LP packages.

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