Furthermore some damage is done to each bottle each time it is moved - thereby decreasing the life of the bottle.

Besides this, the operation of each distribution centre (depot) that is divorced from the central distribution centre costs a great deal of money. This incremental cost as compared to using the centralised distribution centre includes the cost of operating labour, security, checkers, managers, forklifts, control personnel etc.

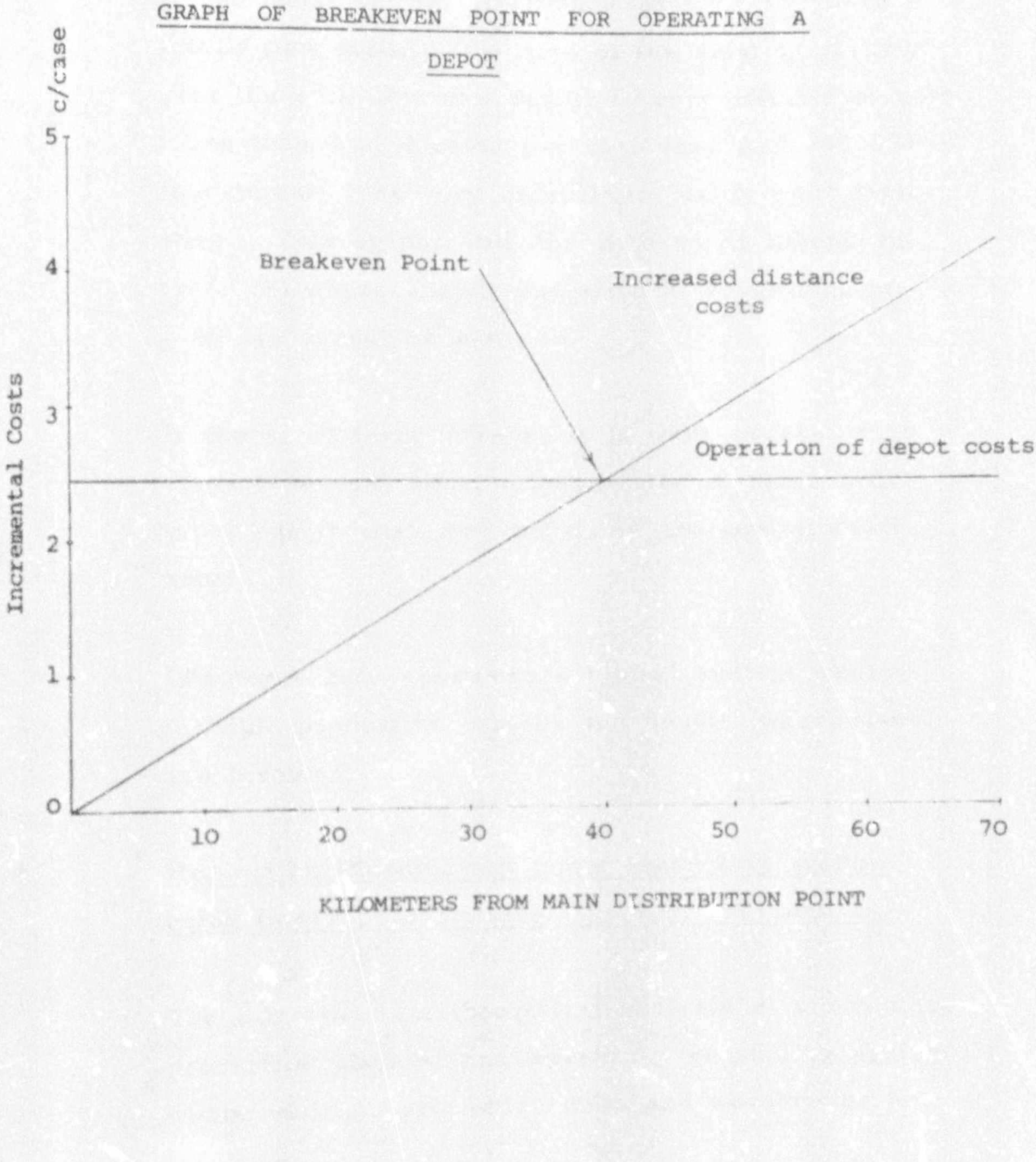
Typically a depot distributing 4 million cases per annum would incur an incremental cost of ± R178 000 p.a. (or 4,5c/case) (depot based 10 - 15 km from production centre).

Fig: 4.5.1. shows a breakeven chart indicating at what stage a depot separated from the main distribution centre would become feasible.

Although the breakeven point shown is at ± 40 km away from the main distribution centre - the actual graph is very shallow and a movement of 10 km - 20 km in either direction will make very little difference. (See ref. 15 for detailed cost breakdowns. However even if one's factory is too small it is difficult to justify using a depot in close proximity to the main distribution centre.

FIG : 4.5.1

GRAPH OF BREAKEVEN POINT FOR OPERATING A DEPOT



If one considers that if discounted over 15 years a totally new facility (the size of the existing facility plus the size of a new depot) is very unlikely to cost more than 3 to 4 cents per case (say R10 000 000 investment) it is very difficult to justify split facilities. This agrees with the findings of Libenberg (ref. 15) where a split operation at a distance of ± 50 km cannot be justified.

In the short term however it is often necessary to operate several distribution centres in close proximity due to cash flow problems and capital available.

Chapter 4.5.2. considers a typical system where multiple production centres and depots (warehouses) are involved.

4.5.2. Production Planning and route scheduling system using linear programming (see ref. 7, 11 and 14).

The following is a theoretical analysis of a combined production planning and warehouse scheduling system where multiple production units and warehouses are involved.

This system can be converted to a warehouse to outlet scheduling system by simply changing the producer in this analysis to the warehouse, and the warehouse in this analysis to the outlet. This will however (as will be shown in the analysis) be impractical due to the vast number of variables involved.

The entire system is applicable to a large beverage manufacturer (excess of 15 million cases) in an urban area (such as Coca Cola Johannesburg with 3 production centres and 5 warehouses).

In such a situation one will normally find that some of the various production centres can produce only some of the many products and product types sent to the warehouses. This possibility is considered in the latter part of this analysis.

4.5.2.1. Assumptions.

The cost of transport of a case of product is the same for all product.

The cost of producing a specific product type does not vary

Costs and efficiencies do not vary over shifts (normal time)

Inventories at the warehouses have already been set

Total production capacity is equal (or exceeds) the demand - single, double, triple shifts with or without overtime

Sufficient empty glass returns with each shipment from the warehouses to allow production to continue.

Any production centre may supply any warehouse.

Each production centre has a given production capacity (and cost) and each warehouse has a given maximum inventory capacity.

4.5.2.2. Analysis

Aim

To minimise total production and distribution costs

Given

n plants	i = 1 to n plants
m warehouses	j = 1 to m warehouses
p products	p = 1 to p products

Let:

Xijk	=	No. of cases of product k produced at plant i and transported to warehouse j.
Rik	=	Cost of cases using regular time production of product k at plant i.
Tij	=	Cost of transport of cases of product from plant i to warehouse j.
Cijk	=	Total cost = (Rik + Tij)
Bi	=	Production capacity of a plant.

$$Bi = \sum_{u=1}^{Li} tu \; LSu \; Eu \; / \; CS$$

Li = No of lines in plant i

tu = total time available

LSu = Line speed of uth line

Eu = Line efficiency

CS = Case Size

Bi is normally an easily determinable figure.

Djk = Demand forecast - demand for product k at warehouse j

Djk may be found from the following formula

$$Djk = Fjk + Pjk - Ijk + Sjk - Qjk + Ajk$$

Pjk = Extra promotional sales

Ijk = on floor inventory

Sjk = Safety Stock

Qjk = No. of cases on order but not yet delivered

Ajk = Seasonal inventory adjustment (if necessary)

Fjk = Forecast of demand - found from previous history using various forecasting techniques - such as exponential smoothing or plain linear regression etc.

../37

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Ajk = Seasonal inventory adjustment (if necessary)

Fjk = Forecast of demand - found from previous history using various forecasting techniques - such as exponential smoothing or plain linear regression etc.

Aik = Gearing factor - i.e.
Should it be necessary to modify Bi - which is a standard machine speed - because of product type, size, and shape, a gearing factor Aik may be used which is proportional to the new speed.

4.5.2.3. Type 1

Assuming every plant can produce every product

We must attempt to minimise an objective function (Z) such that the sum of total costs will be a minimum.

i.e. $$Z_{min} = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C_{ijk} X_{ijk} \quad \text{--- Eq A}$$

Constraints.

Demand constraint
i.e. Production = Demand $$\sum_{i=1}^{n} X_{ijk} = D_{jk}$$

j = 1 to m
k = 1 to p
i = 1 to n

Capacity constraint $$\sum_{j=1}^{m} \sum_{k=1}^{p} A_{ik} X_{ijk} \leq B_i$$

No negatives $$X_{ijk} \geq 0$$

Aik = Gearing factor - i.e.
Should it be necessary to modify Bi - which is a standard machine speed - because of product type, size, and shape, a gearing factor Aik may be used which is proportional to the new speed.

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Constraints.

Demand constraint
i.e. Production = Demand

$$\sum_{i=1}^{n} Xijk = Djk$$

j = 1 to m
k = 1 to p
i = 1 to n

Capacity constraint

$$\sum_{j=1}^{m} \sum_{k=1}^{p} Aik\, Xijk \leqslant Bi$$

No negatives

$$Xijk \geqslant 0$$

This is the format of a straightforward linear program which can easily be soved by many different types of computer packages.

In fact we have nmp decision variables and mp+n constraints.

This program is likely to increase linearly in size with the number of variables and exponentially ($\pm$ to power 3) with an increased number of constraints.

On closer examination one can in fact see that this is the generalised transportation problem which may be solved using a very simplified algorithm - see ref. 7 and 11.

If the number of variables and constraints are large the transportation algorithm is probably the only practical way to solve this problem.

However in real life it is very seldom that all the plants would produce all products. It is far more likely that some products are special to certain plants only (e.g. labelled product vs ACL Products). This means that the entire linear program becomes far more complicated.

Of course if one can eliminate the possibility of more than one plant supplying a given product the total solution set can be considerably reduced.

Also half cases and shifts do not in reality exist and must be manually smoothed after the theoretical solution has been found.

Sensitivity analysis of the linear program can be done by slightly varying various parameters (costs and production data). This is strongly recommended as this type of linear program can be very sensitive to the cost data.

4.5.2.4. Type 2

Let us assume one of the production centres cannot produce all the products sold (e.g. the separation of canning facilities from bottling facilities).

This means that the "specialist" plant that can make the product must distribute this product. It may be that two out of four plants can produce a specialised product. The products must then be allocated accordingly.

Let us split the products where

Products 1 to r are regular products

Products r + 1, r + 2 to p are special products which can only be produced at plants 1 to w ($w \leq n$ the total number of plants)

Type 2 example 1

Specialised production equipment is used only for special products - no regular products are run on the lines - e.g. canning line only.

SBi = capacity to produce special products at plant i

Main Problem

Subproblem 1

Regular Products Only

$$\text{Min } Z_1 = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{r} Cijk\ Xijk$$

(as previous see Eq A)
(same constraints)

Subproblem 2

Special Products Only

$$\text{Min } Z_2 = \sum_{i=1}^{w} \sum_{j=1}^{m} \sum_{k=r+1}^{p} Cijk\ Xijk$$

Demand constraints $\sum_{i=1}^{w} Xijk = Djk$

$j = 1, 2 \text{ --- } m$
$k = r+1,\ r+2,\ r+3 \text{ --- } p$

Capacity Constraints $\sum_{j=1}^{m} \sum_{k=r+1}^{p} Aik\ Xijk \leq SBi$

$i = 1, 2 \text{ --- } w$

And of course $Xijk \geq 0$

These two problems can then be computed separately.

Type 2 example 2

If a special plant can produce a special item and a normal item (such as a generic labelled bottle and a standard bottle), the problem must be approached differently, i.e. the two solution functions must be added to give a new solution

$$\text{Min } Z_3 = Z_1 + Z_2$$

or $$\text{Min } Z_3 = \sum_{i=1}^{w} \sum_{j=1}^{m} \sum_{k=1}^{p} Cijk\,Xijk + \sum_{i=w+}^{n} \sum_{j=1}^{m} \sum_{k=1}^{r} Cijk\,Xijk$$

Constraints

$$\sum_{i=1}^{w} Xijk = Djk \qquad j = 1, 2 \text{ --- } m \quad k = r+1, r+2, \text{ --- } p$$ (Demand constraints) (of special products)

$$\sum_{i=1}^{w} Xijk = Dijk \qquad j = 1, 2 \text{ --- } m \quad k = 1, 2 \text{ --- } r$$ (regular demand) (constraints)

$$\sum_{j=1}^{m} \sum_{k=1}^{p} Aik\,Xijk \leq Bi \qquad i = 1 \text{ to } w$$ (capacity constraints -) (plants producing all) (products)

$$\sum_{j=1}^{m} \sum_{k=1}^{r} Aik\,Xijk \leq Bi \qquad i = w+1, w+2 \text{ --- } n$$ (capacity constraints) (for plants producing) (regular products)

And $Xijk \geqslant 0$

Further examples may be done depending on the individual situation.

../42

Should however it become necessary to include overtime in the total concept - again a linear program can be developed to minimise the amount of overtime required.

If Y_{ijk} = Quantity of product produced on overtime in plant i and shipped to wareho...

O_{ik} = Overtime production cost for product k at plant i

C'_{ijk} = $O_{ik} + T_{ij}$ = Total cost of overtime production and distribution

B'_i = Allowable overtime capacity - i.e. same as B_i but time variation

The minimum total cost will then be:

Z Minimum = Z normal time + Z overtime

$$= \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C_{ijk} X_{ijk} + \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C'_{ijk} Y_{ijk}$$

Demand constraints:

$$\sum_{i=1}^{n} (X_{ijk} + Y_{ijk}) = D_{jk} \qquad j=1,2 \ldots n, \quad k=1,2 \ldots p$$

regular time capacity constraints:

$$\sum_{j=1}^{m} \sum_{k=1}^{p} A_{ik} X_{ijk} \leq B_i \qquad i=1,2 \ldots n$$

overtime capacity constraints:

$$\sum_{j=1}^{m} \sum_{k=1}^{p} A_{ik} Y_{ijk} \leq B'_i \qquad i=1,2 \ldots n$$

and X_{ijk} and $Y_{ijk} \geq 0$

../43

Again many variations of the main production program can be done - including special products, more shifts, and even larger machines.

However if too many alternatives are included the problem may become so large that it will not be easily solved on a computer (or be worth while).

4.5.2.5. Cost and Practicability

Take a typical setup in R.S.A. where 3 production centres and 5 warehouses are involved and some 40 packages are produced.

No. of variables = n x m x p = 3 x 5 x 40 = 600
No. of constraints = mp + n = 5 x 40 + 3 = 203

IBM estimate that a problem this large, and without any major complications will take ± 25 000 to 30 000 c.p.u. seconds (IBM 360 model 67). At today's prices this could mean as much as R10 000 per run.

If we were to take the analysis further and consider distribution from the trucks to the outlets we would be looking at ± 200 trucks, 40 packages and 10 000 outlets.

No. of variables = nmp = 200 x 10 000 x 40 = 80 000 000
No. of constraints = mp + n = 40 x 10 000 + 200 = 400 200

../44

The cost of running one program would be enormous - probably in excess of any computer system invented to date.
Thus, unless major simplifications can be made to the system it is unlikely to ever be practical to implement.
However, if the beverage company does have access to a large computer rig-up and does have some excess time it might well be worth investigating such a system.

4.5.2.6. Graphical Solution

The following is a graphical algorithm (ref. 14) which will give a solution (not necessary optimal) to the previously mentioned problem.

Assumptions

All plants are of approximately equal capacity and warehouses are consistent with the plant capacities.

No special products are produced.

Method

Find the sum of average production costs and transport costs from every plant to every warehouse.

Draw contour lines of constant total costs around each plant.

../45

Now contour lines of adjacent plants will intersect - and at points of equal cost a boundary line of intersecting points can be found.

Each plant can then serve each warehouse within that boundary.

Arbitrary adjustments can then be made to satisfy areas where warehouses and production centres are not totally compatible and where special products are produced.

4.5.2.7. Aggregate Planning

The following is a further rough form of analysis that may be used to try and work out the best available routing concepts.

Dj = Demand at warehouse j (average over all products)
Xi = Production capability plant i (average over all products)
Ri = Production costs at plant i (average over all products)
Tij = Transport costs from plant i to warehouse j.

Now the following information can be tabulated - Assuming 2 plants and 2 warehouses

PERIOD (Month)	D_1	D_2	X_1	X_2	Product $X_1 \leftarrow D_1$	Product $X_1 \leftarrow D_2$	Product $X_2 \rightarrow D_1$	Product $X_2 \rightarrow D_1$
TOTALS								

TOTAL COSTS can then easily be calculated once the total amount of product moving from and to each warehouse has been estimated in the table above. (see page 45.)

The entire process can then be repeated until a best solution is found.

This method is purely mechanical and while it will certainly not give the optimal solution it will serve as a very good guide.

Furthermore no computer is necessary to obtain results.

4.6. WAREHOUSE LAYOUTS

4.6.1. Theoretical

The best warehouse layout must be one that minimises the distances travelled by the forklifts etc. between the production and stacking area, the distribution and stacking area and maximises the space available for storage.

In order to minimise the movement of forklifts between production and stacking it is necessary to keep both the finished products and empty containers as close as possible to the production facility. Furthermore as it is best to fully utilise the forklift in both directions of its travel, it is also necessary to keep the empties and fulls as close as possible to one another.

The moving warehouse concept is shown in Fig: 4.6.1. High volume products are kept close to the production area, thus further reducing forklift movement.

4.6.2. <u>In Practice</u>

In reality very few warehouses resemble Fig: 4.6.1. Because of the high rate of growth of the beverage industry (up to 100% between 1970 and 1978) very few factories have space inside their warehouses to store their empty bottles. This means that empties are kept outside in the rain and fulls inside under shelter. Furthermore empty bottle inventory is very seasonal - being at a maximum in June - July and at a minimum in December when most of the bottles are in the trade.

Fig: 4.6.2. shows a typical existing soft drink factory with warehousing and materials flow, (courtesy LTX Minerals Lichtenburg). As can be seen very little attention has been paid to materials flow and massive expansion has meant restriction in all areas.

4.7. <u>FORKLIFTS AND TROLLEYS</u>

The advent of the forklift had perhaps the most revolutionary effect on warehousing in the beverage

FIG : 4.6.1

WAREHOUSE LAYOUTS

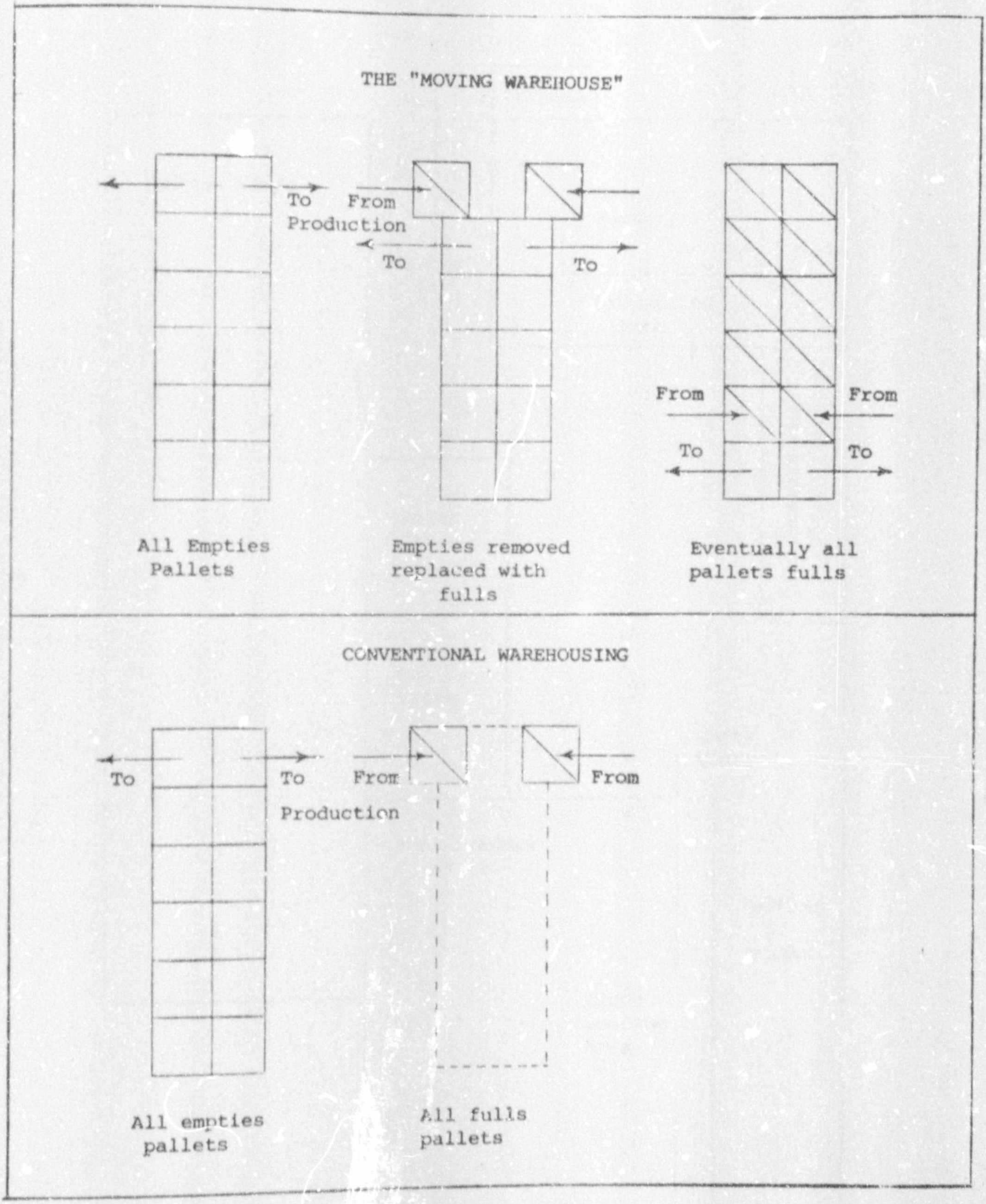
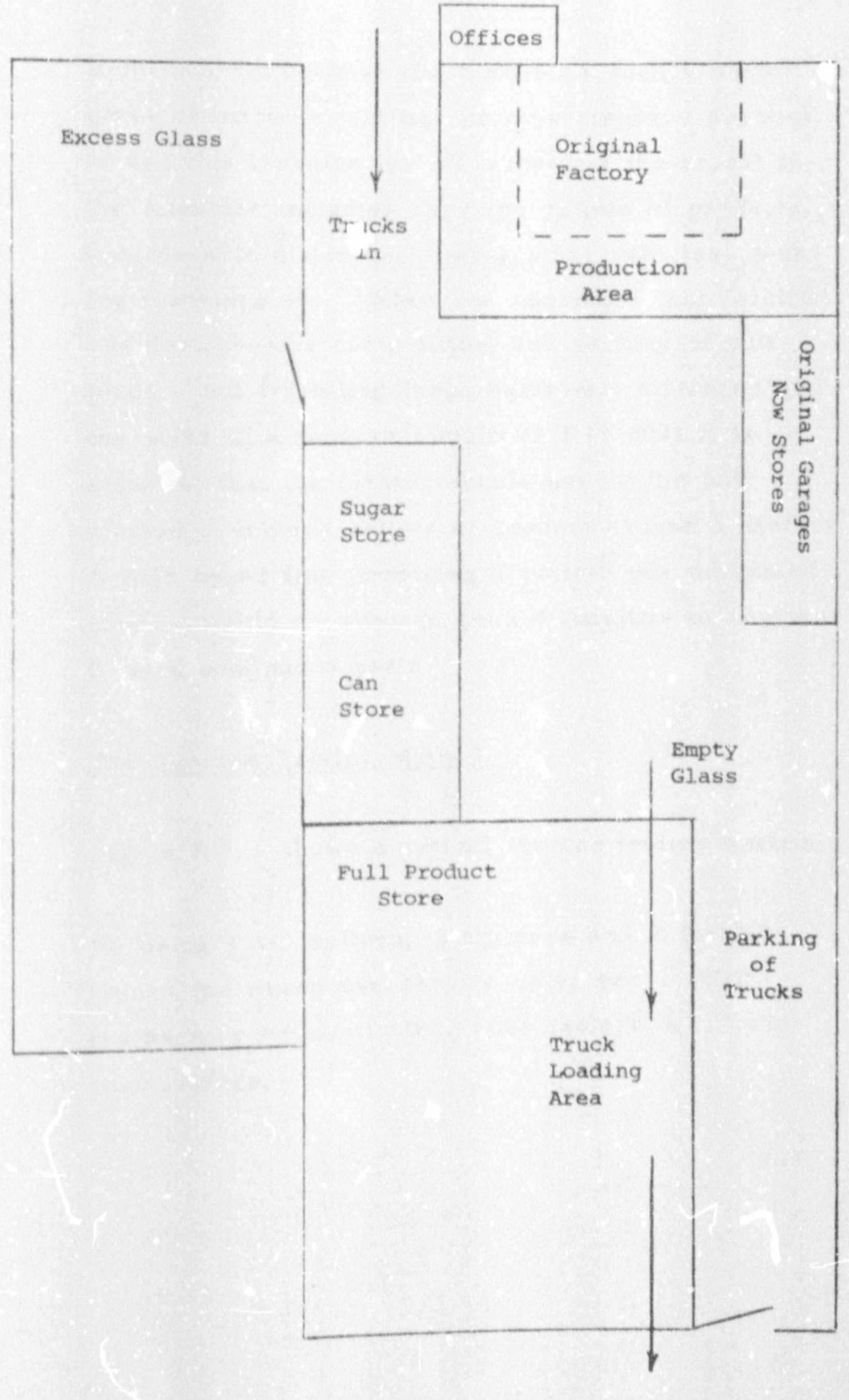


FIG : 4.6.2

EXISTING FACTORY LAYOUT - LTX MINERALS (LICHTENBURG)



industry.

Today in a large factory a fleet of up to 30 forklifts is used to continuously move product around the warehouse, stack product and load trucks.

Unfortunately because the forklift is such a useful piece of machinery it has become standard practice to use this machine for all materials movement in the factories including carrying pallets of products considerable distances, towing other vehicles, jacking machines etc. When one considers that forklifts are designed for basic lifting and shifting of unit loads - not travelling large horizontal distances and the price of a modern forklift (± R17 000) it is apparent that the forklift should not be the only method of moving pallets of product around a factory. A high speed line producing 2 pallets per minute of product would on average need 4 forklifts to service it on a continuous basis.

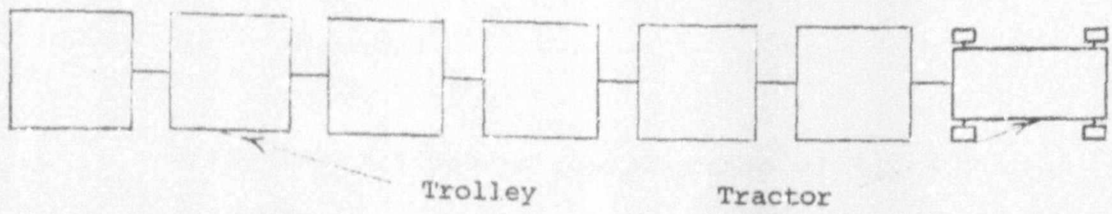
4 7.1. The Tractor Trolley Method

Fig: 4.7.1.1 shows a typical tractor trolley system.

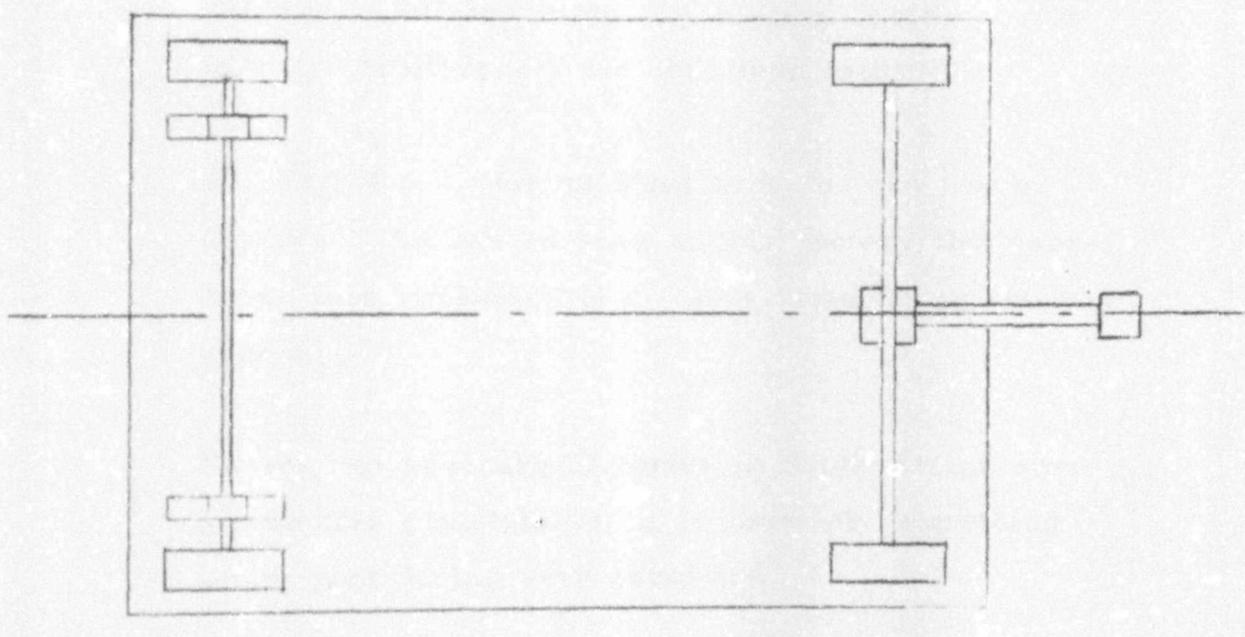
By using ± 16 trolleys, 2 tractors and 2 forklift trucks for warehouse service only, two forklift trucks may be eliminated. See table 4.5.1.2. for cost savings.

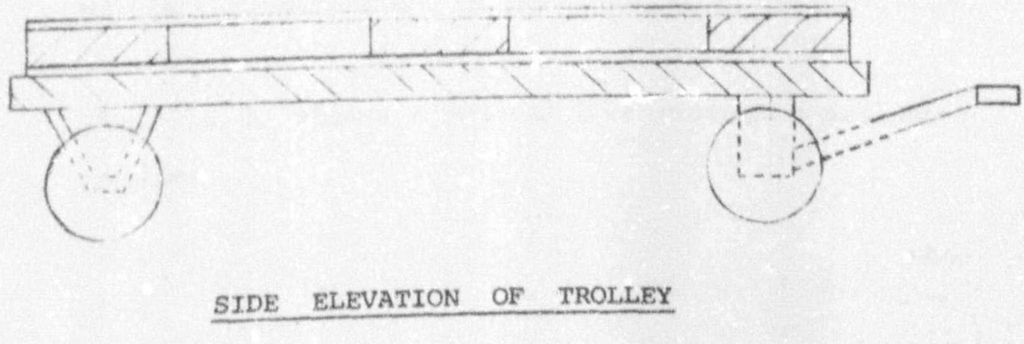
FIG : 4.7.1.1

THE TRACTOR TROLLEY SYSTEM



PLAN OF TROLLEY





SIDE ELEVATION OF TROLLEY

Table 4.5.1.2.

Cost Forklift (2)	R16 000	Cost of 4 Forklifts	R64 000
Cost Tractor (2)	R 5 000		
Cost Trailer (16)	R 600		

Immediate savings in capital outlay of R12 400 can be made.

This saving is considerably increased as the distances between the various stacks of pallets is increased. Furthermore, the running costs of tractors and trolleys are far less than forklifts.

See Fig: 4.6.2. for an ideal area for the use of trolleys. As can be seen at this factory the warehouse is considerable distance from the production centre.

As yet, no beverage factories in South Africa operate on this principle but it is certainly something worth considering very carefully.

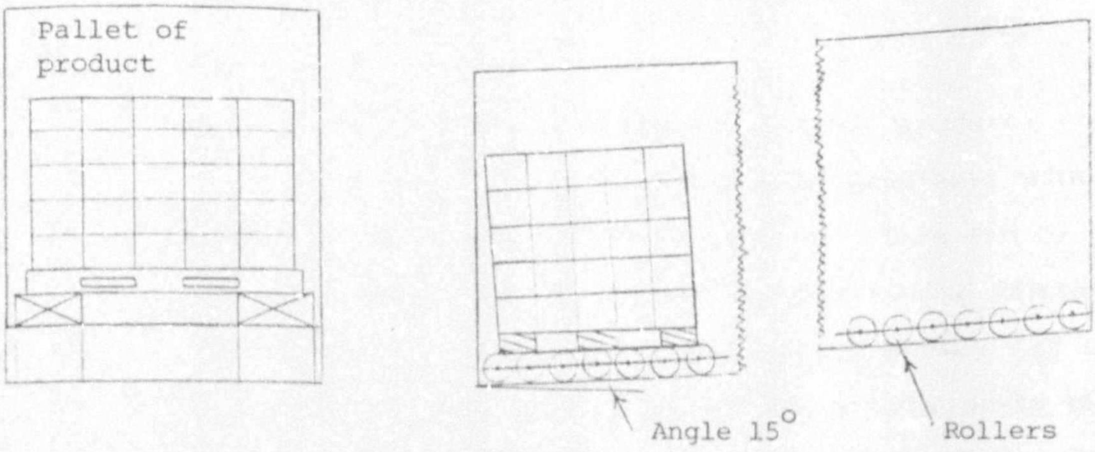
4.8. LIVE STORAGE

Perhaps the greatest advancement in material handling within the warehouse is the concept of live storage.

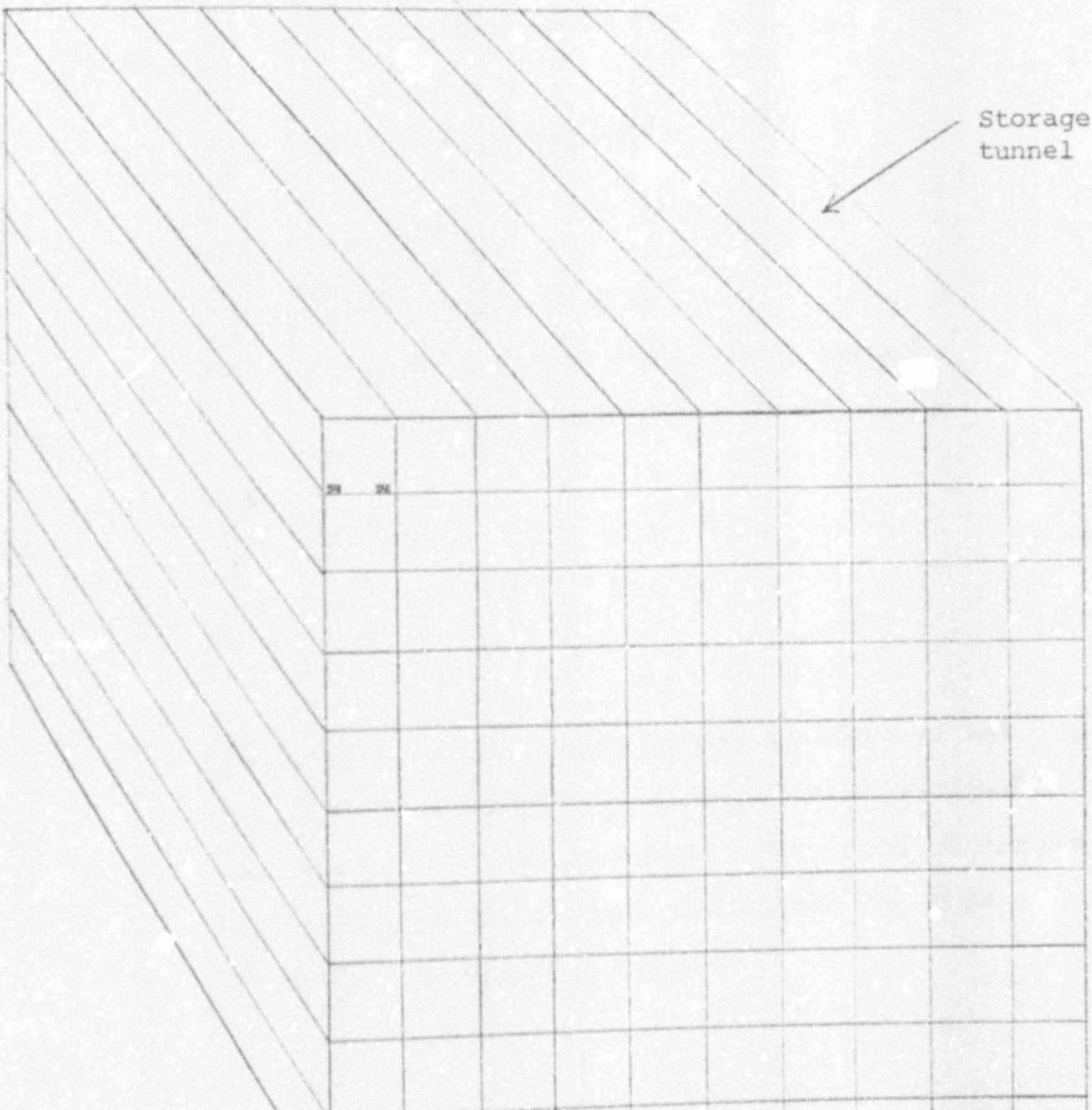
Fig: 4.8.1. shows a typical live storage warehouse concept.

FIG : 4.8.1

SCHEMATIC DIAGRAM OF LIVE STORAGE OF PALLETS



DETAIL OF TUNNEL



Live storage of heavy pallets of bottles products (± 1 ton ea.) can cause considerable problems with the rollers used to move the pallets. This led to the development of the "dolly" system by the Mitsubishi Company in Japan. This system makes use of a dolly (a trolley type of truck) which transports the pallets within the storage tunnels - rather than using standard roller conveyor. There are also several other types of live storage systems in operation throughout the world.

Advantages of live storage:

First in First out.
Considerable space saving.
Easy stock control and rigid stock control.
Lends itself to fully automated warehousing.

Disadvantages:

Cost.

[illegible] 8. 3. shows typical costs involved in the con-s[illegible]tion of a large live storage warehouse and a comparison of these costs with the costs of conventional storage for a plant storing 40 000 pallets of product (fulls and empties).