EFFICIENT STOCK PILING OF 40 MM SHELLS

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ABSTRACT

A problem was posed as to discuss efficient stock-piling of 40 mm shells. There is, in fact, no data from which emergency requirements can be deduced. A figure has been quoted by Army authorities that $\bar{E}$ rounds per month are required during an emergency. The size of the emergency stock-pile will depend upon the difference of the normal peacetime production and the aimed war-time production, and also on the time taken for the crash programme of emergency production to come into fulfilment. In addition the delivery time from factories to the stock-piles is also to be kept in view. It is surmised that the lead time will be about 6 months and delivery time about 2 months. Thus the emergency stock-pile should roughly be $(\bar{E}-P) \times 8$ where P is the installed capacity in peacetime. There are some minor additional terms from probability considerations. The actual size of stock is given in equation (*iii*). Once the emergency production has been set up and regular deliveries are being obtained, the size of the stock-pile is governed by economic considerations regarding cost of storage and replenishment. By adjusting the number of times per year the stock-pile is to be replenished, one can conveniently adjust the stock level during an emergency to be about the same as the level of the initial stock-pile, thus obviating administrative difficulties and to some extent the cost factors are also optimised in the process. The peacetime requirements of stock are, naturally, very small and can be met by a fraction of the installed capacity in the peacetime. The problem still exists as to how to build the emergency stock-pile when the current production is theoretically just sufficient to cover training requirements and wastage requirements of the stock-pile. Various suggestions are discussed. Besides working to the full installed capacity, a proportion of assigned civilian sector should be converted to this production for a limited period, and in addition, the wastage rate should be reduced considerably by a simple artifice of storing of shells without the tracer ignitor etc. which can be stored separately in an unfilled condition. In this manner the deterioration is

very little and most of the surplus production can go towards building stock-pile. In case most of the stock-pile is in unfilled condition, provision will have to be made for increasing filling capacity considerably on a crash basis on the start of an emergency. The filling work will have to be done at the stock-piles.

Emergency Stock-Pile during Peacetime

The Army has surmised that the emergency requirements of 40 mm shells are (E) rounds per month. At present the Director-General of Ordnance Factories can deliver a maximum number (p) per month. His installed capacity is (P) per month and full production can be reached perhaps in 3 months (L_1) in a linear increase. In order to receive supply of $\bar{E}$ per month in an emergency, the productive capacity has to be increased, say, five fold. It is not economical to increase the installed capacity under D.G.O.F. by a factor of five and then to allow this machinery to remain idle. Even in industrially advanced countries, the emergency requirements are met by diversion of civilian resources to such uses. The conversion drill should be established in consultation with manufacturers of civilian production since, for example, it took Indian Railways three years to tool up for Defence production during the last war. The main hurdle would be lack of pre-planning, lack of supervisor staff, lack of prior stocking of necessary gauges and precision tools. In peacetime one can allocate various Defence requirements to suitable peacetime industries who should plan in such a manner that they can divert substantial means of production in an emergency to Defence needs. In case no serious measures as above are taken in the near future, one can imagine that in view of current speed of industrialization of the country, the civilian firms will take about one year to satisfy Defence needs. Assuming that serious measures are taken as regards planning, equipping with necessary gauges and training etc, this period can be reduced to six months (L_2).

Thus the stock pile should be as follows :—

$$S = \frac{P-p}{2} L_1 + (\bar{E} - P) L_2 - f(\bar{E} L_2) \quad . \quad . \quad . \quad (i)$$

where f is the fraction of average production in first L_2 months of production.

Assuming exponential build-up of conversion to Defence production f can be shown to be $\frac{1}{\ln \bar{E}}$

To reduce the stock-pile given in equation (*i*)

P should approach $\bar{E}$ .. .. (*a*)

and L_2 should be small .. .. (*b*)

The condition (*a*) is not feasible from economy considerations.

The condition (*b*) can be improved as follows:—

(*i*) Ear-mark civilian sector that is to go in for production of a specific article like 40 mm ammunition.

(*ii*) The industry should consult with D.G.O.F. and a comprehensive plan for switching over to Defence production be drawn up covering all aspects like availability of raw materials, skills, tools, etc. Any plausible bottle-necks be ameliorated from start.

(*iii*) Some of the supervisory staff in the Industry be seconded for short time to the D.G.O.F's production units so that they are ready at short notice to assist in change over.

(*iv*) Some percentage of assigned civilian sector be switched over to Defence Production for the current requirements of building stock-piles.

Instance can be cited from U.K. and other countries where change over was affected within a month or less.

The size of the stock-pile as indicated is good enough if one is concerned only with the stock-pile at the Factory. Actually emergency stockpiles will be scattered all over the country so that speedy deliveries can be made to strategic areas. If the production gets into stride after a period L_2, a further period D will elapse in pipe line, *i.e.* between delivery at factories and receipt at depots. This may be a period of one month in peacetime and 2 months (under reasonably efficient conditions on the Railways) during emergency. As the emergency progresses, the shortages in wagons etc. are likely to be offset by better management out of experience and delay time can perhaps not deteriorate too much. Thus the stock-pile should be

$$S = \frac{P-p}{2} L_1 + (\bar{E} - P)L_2 + \bar{E}.D. - \frac{\bar{E}\, L_2}{\log_n \bar{E}}$$

$$= \frac{P-p}{2} L_1 + \left\{ \bar{E}\left(1 - \frac{1}{\log \bar{E}}\right) - P \right\} L_2 + \bar{E}.D. \quad . \quad . (ii)$$

There is also an additional term on account of probability variations of emergency requirements during the period $L_2 + D$ (we can assume $L_2 > L_1$). Assuming the actual requirements $\bar{E}$ per month to follow Poisson Distribution[1] we have to guard against a certain chance that $\sum_{L_2+D} E$ over-shoots the stock-pile. This may be calculated as follows. The chance of average of (L_2+D) values of E exceeding $\bar{E}$ by the amount $1\cdot64\sqrt{\frac{\bar{E}}{L_2+D}}$ is less than 5% from statistical tables which is fairly reasonable for such estimation. So we may add a corresponding term and get finally

$$S = \frac{P-p}{2} L_1 + \left\{ \bar{E}\left(1 - \frac{1}{\ln \bar{E}}\right) - P \right\} L_2 + \bar{E}.D + 1\cdot64\sqrt{\bar{E}.(L_2+D)} \quad (iii)$$

This is of the same order as $(\bar{E}-P)(L_2+D)$ which can be used as an approximation to above formula, under assumption that L_1 is negligible and $D<<L_2$.

Stockpile after Emergency Production has been set up

Once the emergency production has been set up and pipe line has started delivering goods at the depots, the protection against L_2 & $\bar{D}$ referred to above are not necessary. Now the size of the stock-pile has to be calculated from the following factors:—

(*a*) Considerations of economy in transportation and storage of requirements.

(*b*) Fluctuations in delivery time.

(*c*) Variations in the monthly rate of off-take E.

(*a*) We must first restrict ourselves to one of the many stock-piles that are to be built at various strategic places. Supposing (x) is the fraction of total expenditure per year of 12 $\bar{E}$, passing through this particular stock-pile, (x) would be of the order of 1/12 (in case there are likely to be 12 major depots). During the emergency the factories must have a policy to keep filling wagons to capacity and sending goods trains off, turn by turn, to various stock-piles. The usual criterion that restocking cost per year should be equal to the average stocking cost of inventory is not so important since inventory costs at stock-pile are negligible whereas these are considerable at factory and it is uneconomical to transmit rounds in loads less than a full ammunition train.

If there are q wagons in a goods train whose main function is to deliver 40 mm ammunition to a particular depot, (q may be of the order of 30 since some stuff may have also to be sent to the same depot from one or two factories in the neighbourhood in the same goods train), and w ($\sim$ 1000) is number of rounds loaded in each wagon, the number of times in a year the stock is replenished at this depot is

$$n = \frac{x .\ 12\ \bar{E}}{q \times w} \qquad \text{.. \quad .. \quad ..} \qquad (iv)$$

In a practical example assume $n = 5$.

(*b*) Since the delivery time is assumed to be D months, a fluctuation in delivery time is likely to occur. Experience may dictate that one should guard against 100 per cent fluctuation which is understandable as it only amounts to saying that the factory may miss on one consignment on account of pressing requirement of another stock-pile while the requirements of depot under discussion remains steady. Thus a total protective stock of $\bar{E}$ D should also be kept.

(c) Now $\frac{12}{n}\bar{E}$ total stock-pile is all right if the demand in this period of $12/n$ months remains steady around an average of $\bar{E}$ but this is not rigid. The demand may show some variation. It is well known in similar analysis that requirement E per month follows Poisson Distribution which states that

$$\Phi(E,\bar{E}) = \frac{e^{-\bar{E}}\,\bar{E}^{E}}{E!} \quad \cdots \quad (v)$$

where E is emergency requirement per month, $\bar{E}$ is average requirement and Φ is the probability of occurrence of E. So that we guard against a chance of one in 20 (assume the emergency to be 4 years long (there are five deliveries per year) we should be prepared to supply that E_o for which $F = (1 - \text{cumulative } \Sigma\Phi)$ is less than 1/20.

Below a table for F and E is given for $\bar{E}=10$ units. (Assume D of the order of one month and 10 main groups of demands to occur on the average in D periods.)

E_o units	$\Phi(E_o,10)$	$\sum_{o}^{o}\theta$	$F = 1 - \sum_{o}^{E_o}\varphi$
0	·000045	·000045	·999954
1	·000454	·000499	..
2	·002270	·002769	..
3	·007567	·010336	..
4	·018917	·029253	..
5	·037833	·067086	·932914
6	·063055	·130141	..
7	·090079	·220220	..
8	·112599	·332819	..
9	·125110	·457929	..
10	·125110	·583039	·416961
11	·113736	·696775	..
12	·094780	·791555	..
13	·072908	·864463	·135537
14	·052077	·916540	·083450
15	·034718	·951258	·048742
16	·021699	·972957	·027043

Since F is almost 1/20 when E_o is 15 units as against $\bar{E}$ being 10 units, we should be prepared to meet the E_o in our protective stock. This is possible if in place of protective stock standing at $\bar{E} \times D$, it should stand at $1 \cdot 5\bar{E} \times D$, D being of the order of one month.

Summing up *a* to *c*, the provision of storage space for total stock-pile should only be

$$\frac{12\bar{E}}{n} + 1 \cdot 5\bar{E} \times D \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (vi)$$

Actually it would be best to match peacetime emergency stock and emergency time stock so that stock-pile facilities do neither become redundant nor is there rush for creating more storage facilities. This adjustment is possible by adjusting q and, therefore, n or perhaps L_2 when absolutely necessary.

Peacetime Requirements for Training and Upkeep of Emergency Stock

If peacetime training requirements are B and a fraction α of the emergency stock in storage etc. per annum is wasted then peacetime requirements per month are

$$R = \frac{B + \alpha S}{12} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (vii)$$

In our typical case α can be taken as $0 \cdot 1$.

It is good to adjust that R is equal to peacetime production. $\alpha = \cdot 1$ thus permits adequate turnover once the stock pile has been built in peacetime. From monthly requirement of R we can evaluate active stock as before.

Here since quantity involved is not very large, we have to balance storage costs with replenishment costs. In peacetime it is quite feasible to send even single wagon loads and there is no real need of sending ammunition trains destined to single depots. If the cost of storage per round is C and of transporting a wagon is $l(q)$, (The cost of transporting l is a function of q, number of wagons transported at one time), then

$$\frac{12 \times R}{w} \times l(q) = \frac{12 \times R}{n \times 2} C$$

$$\text{which gives} \quad n = \frac{C.w}{2\, l(q)}$$

Actually there will be a range of values of n for different q. But range will now be very large and a value of n can be selected. The storage cost per round can be determined from the expenditure on a depot and average holding of the depot Assume w=1,000, and l is available from railway receipts for payment per wagon. Thus the active stock from equation (*vi*) is

$\frac{12}{n} R + 1 \cdot 5R \times D'$, value of D' is likely to be one month in peacetime. Assessing a numerical value 2 for n, the peacetime stock should be $\frac{12}{2} \times R + 1 \cdot 5 \times R \times 1$, which is a very small fraction of stock required in peacetime for emergency.

Means of Building up of Emergency Stock-pile

The present peacetime production p is just enough for peacetime requirements. Thus additional production in peacetime is necessary for building emergency stocks. This problem can be tackled after defining the aimed period in which emergency Stock must be built supposing this period is 2 years plus some lead time. By raising the present production to installed capacity which is possible, one can produce $24\times(P-p)$ extra rounds. This can be substantially increased by educative production in civilian sector. The civil sector in emergency is to produce $(E-P)$ rounds per month. In peacetime with 10 per cent conversion as education for ultimate need, one can get substantial help. Any gap from total stock-pile requirements can best be filled by reducing α, the wastage per year to practically zero from $0\cdot1$. Thus the emergency stock pile can be conveniently built in a period slightly exceeding 2 years by:

(*a*) reducing wastage considerably,

(*b*) raising production to installed capacity, and

(*c*) converting civil industry to the level of 10 per cent wartime conversion.

Regarding (*a*) the obvious steps are keeping the tracer igniter, primer and fuse separately unfilled. This will mean having plans for very rapid development of facilities for filling in an emergency, practically the capacity is to go up 30 fold. This capacity has to function at the stock-pile. After the stock-pile has been developed, the filling can be increased so that turnover of installed capacity is maintained at reasonable level in the interest of workers in this industry. This will also ease upon the requirement of extremely rapid expansion of filling capacity. The civil Industry should continue to work at about 1 per cent level and the D.G.O.F. should climb down to 25 per cent of installed level and α should go up to about $0\cdot05$ as 50 per cent of stock-pile can be maintained filled in ready condition. This will also mean employment of some of the surplus staff from production which has to be cut down when the emergency stock has been built.

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Reference

1. W. F. Hoehning—"Statistical Inventory Control" Industrial Quality Control, **13**, 7 (1957).