The Case of the 'Missing Egyptian

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Techniques of Operations Research that can find meaningful application in the textile industry are Linear Programming and Queueing Theory. After many efforts at getting to 'experiment' with such OR techniques in cotton textile mills in Ahmedabad, only one case for cotton mixing could be successfully conducted on the shop floor of a renowned mill – say, Progressive Mills Ltd. (PML). This case study is described briefly in this paper.

Linear Programming for Enhancing Profitability

Three specific needs for maximizing profitability of textile mills that convert cotton fibres into yarns and yarns into woven fabrics are:

a) To minimize the cost of 'cotton mixing' –different varieties are usually mixed together for spinning a specific count (thickness) of yarn –while keeping the 'quality' of the mixed fibres at the desired level.. The optimum quantities of cotton varieties are determined.

b) To maximize the total contribution from sales of all different counts (products) of yarn while ensuring that the quantities of each count are such that the production capacities at different stages of processing are capable of producing the product mix. The optimum quantities of different counts (products) are determined.

c) To maximize the total contribution from sale of different fabrics (products) while ensuring that the quantities of each type of fabric are such that the production capacities at different stages of processing are capable of producing the product mix. The optimum quantities of fabric variety (products) are determined.

The mixing cost optimization is invariably made on the basis of skill and experience developed over the years by 'specialists' in the cotton based textile mills. Similarly, the product mix optimisation is done based on the experience of the managers (production and marketing) in an ad hoc manner. When thinking in terms of applying the quantitative techniques of Operations Research – Linear Programming in this case - the two major questions that need to be addressed are: Do the conditions to be fulfilled mathematically truly correspond to the technological situations in mill practice? And would the 'more scientific' solution be substantially better than the intuitive experience based solution? Unless these two questions are answered affirmatively, the question of 'applicability' in the sense of ability to implement the OR methodology in day-to-day practice does not arise.

Technological Considerations

Cotton –a short staple fibre of average length 20 mm to 40 mm –is converted into yarn through a series of processes whereby the hard pressed bale of cotton is opened, cleaned, formed into a thick sheet, converted into a sliver (untwisted thick strand of fibres), and gradually made thinner till the final yarn (thread) is obtained as a twisted thin strand that is strong and sufficiently uniform in thickness. The finer (thinner –of higher count) the yarn to be produced, the 'better' should be the quality of the fibre mix. For example, the average fibre length –as one quality measure - needed for spinning 20s count is about 22 mm, while 60s count would need average length of 28 mm.

The quality of cotton is assessed in terms of average length (mm), effective length (mm), average strength (g/tex), and fineness (micrograms per inch) –the more the better for the first three, and lesser the better for fineness. (Several other measures are also available, but they have not helped in defining cotton quality better.) All these are assessed by skilled 'cotton selectors' who hold a bunch of fibres between thumbs and forefingers of both hands and pull them apart. They look at the price and quality to take a decision on buying for use in mixing for a specific count or count group. Since about 1950, these properties are measured instrumentally. These measured values are used to vet or to change the skill-based decision, are stored for record and are also used to decide quantities to be used in specific mixing for a specified count. Purchases were NOT BASED on the measured values till about 1990, mainly because the relatively long time needed to test each property of a cotton and also because a reliable 'index' composed of all four properties was not available to judge the 'quality' of cotton. Even as of 2016, spinning mills that use test results for buying cottons are rare.

Expectations from a 'good cotton mixing' are:

1. Produce yarn of the given count that is good in quality –good strength and evenness, low on yarn imperfections and faults.
2. Give good working –less breakages of strands while processing - during the spinning processes from fibre sheet to yarn, especially at the last stage of ring frames where the final yarn is formed. A worker attends to around 2000 spindles rotating at around 20,000 revolutions per minute and so the yarn breakage rates need to be around 2-4 per 100 spindle hours.
3. Give good working similarly in the processes of weaving, especially on the looms where the fabric is formed (woven). A worker attends to about 16-24 automatic looms where the breakages of warp –vertical – threads need to be less than 2 per hour and of weft –horizontal –threads needs to be less than 0.5 per hour.
4. Give a good appearance and feel to the fabric that is finally produced after bleaching (dyeing, printing), both judged by skilled sales personnel. (Measuring these qualities has been tried successfully, but the instrumentation is unduly expensive and difficult to use as routine.)
5. Give a good strength and correspondingly good service life for the clothes that are made from the fabric; should last for over 2 years with several washings (of different harshness).

Applied research done worldwide over the years from 1930 to 1990 (even till 2016) has shown that only the strength of yarn can be predicted with reasonable accuracy from the measures of cotton quality, the 'working' –i.e. the breakage rates at processes of spinning and weaving cannot be predicted (types and conditions of machines play a major role), and fabric quality and serviceability is also beyond reliable prediction in a quantitative manner.

Given this background, it was decided to formulate the LP problem for cotton mixings on the following basis.

i) Measure only 4 properties of cottons: mean length, effective length, strength and fineness.

ii) Since no STANDARD quality parameters can be established for a given count and its end use, follow the mill practice; i. e. keep the average mixing properties at the same level as the mill has been keeping over the past 6 months or so.

iii) Keep each of the property at its average level: no attempt to be made to form any index by combining the 4 different properties as is needed to predict yarn strength accurately.

iv) Clearly, the weighted average by weights of average lengths of different cotton varieties in the mixing can be considered as the average length of the mixing. In the case of 'effective length' which is obtained as a 'median length' after keeping the 'short' fibres away, such additivity is unclear. Even so, it was assumed to hold, for all practical purposes. The strength, again, need not be additive since the weakest link decides the average strength; here too, additivity was assumed. For the values of fineness –an inverse measure of thinness – weighted average of inverse –harmonic mean –was taken, to bring in true additivity.

v) Decide upon standard value for each property that should be maintained in the mixing to ensure that the desired quality of the mixing is maintained; these are the average values of the mill for the past 6 months.

Even after all these technological and mathematical limitations, we felt that this approach will work because the performance at the mill has been consistently good over years.

The LP Formulation

The mathematical expressions for linear programming consist of an objective function and several constraints. The objective function is to be minimized (or maximized) subject to the constraints. When LP is applied to cotton mixings, the objective is to minimize the mixing cost subject to constraints on quality of mixing, usage of specific cottons etc.

Let c1, c2, c3, ---etc. be the prices of cottons 1, 2, 3, etc. in Rs per kg, and let p1, p2, p3 etc. be the proportions of these cottons in the mixing. Then the objective is to minimize the cost of mixing C given by $C = c1p1+ c2p2+ c3p3$

Where $p1+p2+p3----=1$

The average property of the mixing is obtained as the weighted average of properties of cottons in the mixing. E.g. M, the average length of the mixing is obtained as: $M = m1p1+m2p2+m3p3+m4p4$ if four cottons are being mixed to prepare a mixing.

The constraints on mixing quality can be stated by a number of inequalities like

$m_1p_1+m_2p_2+m_3p_3$ -------- $\geq M_s$.
$e_1p_1+e_2p_2+e_3p_3$ --------- $\geq E_s$
$s_1p_1+ s_2p_s+ s_3p_3$ --------- $\geq S_s$
$p_1/f_1 + p_2/f_2 + p_3/s_3$ ---------- $\geq 1/F_s$

Where m= mean length (mm), e=effective length (mm), s= strength (g/tex) and f= fineness (mcg/in) of cottons while Ms, Es, Ss and Fs are standard values of the properties chosen for deciding the desired mixing quality.

Additional constraints, based on technological judgements, may be put on the use of specific cottons such as $p_4 \leq 0.30$ and $p_1 \geq 0.10$

Using LP for Reducing Mixing Cost at PML

We chose the Progressive Mills Ltd for testing the usefulness of LP to the textile industry because of the following reasons:

- This was a composite textile mill, i.e. a mill where cotton fibres get converted into finished fabric in one premise.
- The mill was famous for excellent quality of fabrics.
- The mill's profit performance was good and the management was willing to take some risk for possible gains through application of OR methods in its working.
- One of their most valued product –white shirting made from cotton mixing using Egyptian cottons –was sort of a branded product in the market.
- Egyptian cottons were expensive, partly because of high quality and also because of being imported (with taxes).
- The mill was unwilling to try out long staple fine Indian cottons that had come recently in the markets, because one was not assured that the quality of mixing will remain equally good. These Indian cottons, equivalent to Egyptian, were substantially lower priced.

Given this situation, we realised that substituting Egyptian by Indian cottons would be very profitable for the PML, if the quality and performance of the mixing to be determined by using LP were to be as good as the mill's existing mixing. If the results were to show that the LP mixing works as well as the mill mixing and shows substantial monetary gains to PML, we will be able to persuade many more mills to adopt LP for optimizing cotton mixings.

Implementation at PML

As researchers from ATIRA –Ahmedabad Textile Industry's Research Association –we approached the Chief Operating Officer of PML for permission to conduct a full-fledged experiment on use of LP to reduce the mixing cost of 44s combed count used for making their prestigious white shirting. The cottons used for this count were all imported, Egyptian and Sudanese, known generally as Egyptian cottons. After getting a feel on the situation, he agreed to permit the experiment and advised us to meet the persons from the cotton testing laboratory and the spinning manager to convince them about the usefulness of LP IF it is found 'to work' as well as the mill's normal mixing. The Testing Lab provided the data needed for establishing the average values of cotton properties of this mixing over the past 6 months, and also provided the properties of the currently used different Indian cottons. Here, the properties of varieties not included in the current mill mixing were also available. The Spinning Manager was accustomed to the traditional mill practice of having no say in deciding the mixing unless something goes drastically wrong with the mixing decided by cotton selectors. Not familiar with either computers or with Linear Programming, he had to agree for this experiment in his department, where a bulk sample will be run on one ring frame to test the yarn quality and end breakage rates. He, very wisely, made a statement," Even if the quality parameters of the 'computer yarn' are seen to be the same as the normal mill yarn, and the breakage rates are acceptably low,

I will not say that the computer mixing is OK! After all, I spin yarns for the Weaving master to weave cloth on looms. On his automatic looms, he is getting 92% efficiency and if the computer mixing gives less efficiency, that will not do." And he was right – even a small reduction in loom efficiency would lead to substantial loss to the mill, thereby offsetting the gains in the mixing cost by using LP.

So, we met the Weaving master also and he agreed to let the computer mixing yarn go through identical pre-weaving processes to run on 4 automatic looms out of the 16 allotted to a weaver, provided that the yarn quality of computer mixing was same as the mill mixing. We also agreed that if the computer mixing yarn was somewhat inferior in quality, we will not go further than spinning.

We applied LP as indicated earlier, but without any constraint on use of any cotton, Indian as well as Egyptian. The result showed that the one costly Egyptian cotton was not needed to fulfill the quality conditions of the cotton mixing for the 44s count. One long staple fine Indian cotton appeared in the LP solution as 33% of the mixing. This LP solution was about 70 pise per kg less expensive than the mill's normal. This was a reduction of about 7% in cotton cost, which constitutes about 70% of the yarn cost for this count. These savings were such that the overall profitability of the mill would have increased by about 4% since this 44s white shirting formed a good proportion of the total production of fabrics in this mill.

Technological Performance

Two things happened as soon as the mill experiment started. Firstly, everyone knew that this LP mixing obtained by using computers is less costly ---it was termed as 'cheap' (inferior in quality) by almost all, especially because there was an Indian cotton in it. Secondly, therefore, everyone expected it to give 'poorer' yarn quality and inferior performance. The entire atmosphere during this mill experiment was loaded against the poor 'computer mixing' versus the good 'mill mixing'. As the computer mixing was processed through the combing operation, with the same machine settings as that used for the mill mixing, the 'short fibre waste' removal was of the same order. Thus, no cost adjustment was necessary in the computation mentioned above. The quality parameters of the yarn turned out to be the same as that for the normal mill yarn, which was the first vindication of the hypothesis that 'equal mixing quality' will result in 'equal yarn quality'. Data were kept on the breakage rates and these, too, turned out to be of the same order as that for the mill mixing. So, the Spinning Manager got satisfied that his department would have no difficulty in running the computer mixing.

But, as he had earlier insisted, the real test was to be at the automatic looms, where the efficiency would need to be equally high for the yarn made from the computer mixing. The Weaving Manager ensured that the computer yarn went through identical processing at the three preparatory processes of winding, warping and sizing. The yarn breakage rates in winding and warping were not different from the mill yarn. One was not sure whether the 'size paste' would need adjustment by way of changing the proportion of different ingredients to suit the changed cotton mixing. However, we had decided in consultation with the Weaving Manager, that we should not do any adjustment to begin with. In case the computer yarn as warp threads gave a little more breakage rate, it would be necessary to 'strengthen' the computer yarn somewhat, by changing the size recipe. It so turned out that the 4 looms on which the computer yarn was used as warp gave the same high efficiency as the normal mill warp yarn.

It may be noted, that these 4 looms were not in any one lot of 16 looms of a weaver: these were spread 1 each in 4 different sets of 16 looms attended by 4 weavers. None of the weavers felt that the computer yarn was any different from the mill yarn ---in fact, they were NOT told that one of their looms had a computer yarn. They only knew that some experimental yarn is being fed as warp on1 of their looms.

At this stage, we, the consulting team from ATIRA, felt quite relieved because the 'cheap' computer yarn had passed some rigid tests with flying colours. But our relief lasted only for a day or so. When we spoke to the management about adopting LP for cotton mixing of 44s count, they were hesitant. The sales personnel had known about this 'cheap' mixing without one superior Egyptian cotton. They were pretty sure that the appearance of the fabric as well as its feel will be pretty poor because an Indian cotton was put in place of the "Superior but Missing Egyptian".

They insisted that the management take this LP experiment till the end point of making their famous white shirting from the computer mixing. They would accept the computer mixing ONLY IF the fabric from that is found at least as good as the mill fabric in terms of feel and appearance.

Subjective Performance

Up to the stage of weaving on looms, the parameters to be compared were objective: measurable with instruments or recordable as numbers (of yarn breakages). When it came to subjective judgements by skilled individuals, the consulting team members were at a great disadvantage. If any of them were to 'feel' the fabric or to judge its 'appearance', our assessment would be considered amateur and therefore not trust worthy! Even the results of so called instrumental testing, elaborate and indirect, on feel and appearance would not help in convincing the rightly skeptical sales personnel. In fact, even the Chemical Processing Master, in charge of bleaching and finishing this super-white shirting, was confident that the computer fabric will not be 'good' enough. We, therefore, designed a 'paired comparison' statistical test based on binomial distribution to let the sales and the chemical processing persons to assess separately the 'feel' and the 'appearance' of the computerized and mill fabrics. Twenty pairs of samples, each with one computer and one mill fabric piece, of about 1 meter by 1 meter were prepared. All 40 pieces were numbered 1 to 40; each pair had either the odd or the even number allotted to computer fabric, using random numbers. The 'experts' were to take each pair for comparison and judge which one of them is 'poor' in quality being judged: either feel or appearance. The decision was 'forced' in the sense that no expert was allowed to say 'do not know' or 'both are equal'.

The identity of these numbers was kept secret and this 'number code' sheet was given to a neutral observer of the test. We chose a mill person from the Testing Laboratory for keeping this sheet and thereafter decoding the results of test. For each expert, the number of correct and incorrect predictions were to be determined. The formula to be used was a simplified version of the Chi Square test for paired comparison where the probability level was kept at 5%. (1 in 20 chance). (A-B) x (A-B)/ (A+B) > 4 where A and B are the number of correct and incorrect assessment of feel/appearance by one observer. (Chi Square test with 1 degree of freedom, the number for 5% error is 3.84. We have simply used 4.0 to err on safer side and called this 'Formula Four' for ready use in mills for testing all variables that can be 'counted' i.e. follow a Poisson or Binomial distribution.)

We requested 6 persons, 4 from sales and 2 from chemical processing, to perform the assessment of feel and appearance. We explained to them the rationale behind the test: essentially, this test is to eliminate any personal bias for or against the computerized mixing that had the superior "Egyptian Missing." We also tried to explain how statistical sampling works. If the two samples were to be identical, the result will be 20 correct and 20 incorrect since a decision has been forced. If the difference is rather large and easily feel-able/see-able, the result will be 40 correct and 0 incorrect. But what happens if an expert gets 30 correct and 10 incorrect? Is the difference between the two kinds of fabrics truly real? Here, the formula needs to be used. (30-10)(30-10)/ (30+10) =400/40=10 which is higher than 4. So, there is good reason to conclude that the two fabrics are different. However, a simple majority of say 25 correct, would not do: Formula Four shows the result to be 100/40=2.5 which is less than 4. Therefore, even a strong 62.5% majority (25 out of 40) would not do!

All this was explained on one day, and the tests were conducted on the next day. It was interesting to note that many a times an expert will take out one sample of the two and say 'this is computer' meaning this one is poorer in appearance or in feel. Our efforts to convey that they should only say 'good' or 'poor' without thinking of mill mixing or computerized mixing did not succeed! After all, every one of the experts 'knew' that the 'Missing Egyptian' will make the fabric poorer!!
Result from each expert was given to the Testing Laboratory evaluator. His decoding for each of the 6 experts showed that in no single case was the 'computer fabric' found to be inferior to the 'mill fabric' when the Formula Four was applied. None of the results showed more than 26 out of 40 for either of the fabrics. This result was declared by the Laboratory Head to all experts in the presence of the consulting team from ATIRA.

Conclusion: the fabric made from the computerized mixing using an Indian cotton in place of one Egyptian cotton is as good in appearance and in feel as the mill fabric with all Egyptian cottons.

AND pandemonium broke loose: none of the experts were willing to accept the conclusion. They said that they did not understand the Formula Four, but had agreed to proceed. Now they do not want to believe the result based on such a formula.

We, as consultants, agreed with them that their non-familiarity with statistical methods made it difficult for them to 'trust' a formula for coming to a conclusion. We then urged them to compare their individual results with each other. The score sheet for each was handed over to him; and they started comparing with each other. If fabric No. 15 from the pair 15-16 was classified as 'poor' by expert X, the same was classified as 'good' by expert Y. Such differences came out so vividly among them all, that they burst out laughing! Like we had explained earlier, a forced decision where the fabrics are identical would naturally lead to such a hilarious situation!! They now realised that the Formula Four is trustworthy!!!

Conclusion

Here is the gist of this case on application of LP to minimizing the cost of cotton mixing keeping quality of mixing at standard level.
Although there existed some technological limitations in formulating the constraints, the LP solution was considered meaningful because it essentially followed the mill practice of using a set of cottons to keep the working of the mill steady and the quality of the final product –the white shirting –at a level accepted by the market with a premium price.
Full-fledged experimentation on a semi-bulk scale showed that the quality of yarn produced from the LP based mixing was good, the breakage rates at all stages of spinning and weaving were comparable to the mill mixing, loom efficiency was maintained and the bleached white fabric ready for sale was as good as the mill fabric in spite of the 'Missing Egyptian' cotton.
The gain in profitability was thus found to be good if LP were to be used for deciding the quantities of cottons to be used in the cotton mixing to keep the cost to the minimum.

We, the consulting team, approached the top management with all these results. They, obviously, were already briefed by the Spinning, Weaving and Chemical Processing Mangers as well as the Chief of Sales on the nature of the trial taken in the mill and the results. When we urged the Top Management to implement LP for cotton mixings on a regular basis for the 44s mixing, and then to extend it to other mixings, their response was illuminating. "We do see that eliminating that one Egyptian cotton has not hurt anywhere in what we can see in the mill, but how would we know that the durability of this fabric made out of cheaper Indian cotton used in the mixing will be as good? If the buyers find that the shirts made do not last long enough after several washings, our mill's reputation will suffer. We do not want to take such a risk."

Linear Programming successfully applied, implementation as routine a complete failure!

Frankly, it would have been possible to logically argue with the Top Management and to demonstrate that, technologically, their fear about serviceability of the shirts made from LP mixing were unfounded. But we also knew that this would not help change the decision. In this mill, the owner cum managing director –the highest authority in the mill –had always claimed, quite rightly, that he makes more profit for the mill than all the rest put together in their own departments, by selecting the right type of cotton at the right time and buying it at the right price. Results from instrumental tests of cotton properties used in LP would need to be used in cotton purchase: a strong interference in his domain of expertise. The ATIRA team had no interaction at all with him earlier, nor would it be possible at this stage of the case. So, the 'Egyptian did not go missing' from the cotton mixing of 44s combed count meant for white shirting of the Progressive Mills Ltd.

After about 7-8 years, the Indian long staple cotton varieties got accepted as 'good' outside India –were exported on a large scale –and also within India. Egyptian and Sudanese cottons were no longer imported and used by most Indian mills. Even in PML, the 'Egyptian went missing' after this time.

Here rests "The case of the Missing Egyptian".

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