Linking technology development with production – A methodology and case histories

S. C. Gupta

Significance and the process of linking technology development with production in the innovation chain are brought out. The individual and joint roles and responsibilities of the development and production agencies are identified. The methodology and attitude used for fruitful interaction between the development teams of VSSC and the different production agencies are illustrated by case histories of different items. A case of unsuccessful production is also presented to bring out the importance of market forces.

GLOBALIZATION of Indian economy has made pursuit of competitiveness by industry of the country an imperative. Generation and utilization of know-how for improved products and services contribute greatly to competitiveness. For this purpose, there has to be a strong team-work between the research and development teams – which generate the know-how, and the production teams – which utilize the know-how. Whether or not the two teams belong to the same corporate body, the team-work has to be meticulous. The data for India on expenditure on R&D by industry, utilization of know-how generated in India and import of know-how brings out unambiguously that there is little support for the generation of know-how in India and most of the need is met by import. India has a vast R&D infrastructure and substantial R&D manpower. India has also achieved impressive successes in developing and utilizing know-how in a number of important fields, such as space and agriculture. Thus, there is inherent capability. What is lacking is an effective harnessing of the inherent capability.

One of the most important functions of research and development is to generate know-how for transfer to industry for production of new and improved goods and services. Acceptance of the know-how by industry spurs R&D. However, acceptance depends on the techno-economic features of the know-how. The know-how has to be mature and comprehensive enough for smooth production. The respective responsibilities of the R&D and production teams during the transfer, production and marketing activities are to be identified clearly and discharged fully. Near certain prospects of attractive profits to the production agency strengthen acceptance. The R&D team can provide adequate information and confidence on the first two features of the offered know-how. As the profit potential of the know-how also depends on factors such as market forces, beyond the control of laboratory and industry, the information generated by the R&D team has to be supplemented.

Lack of confidence in the dependability of the technical information provided by the R&D team is often a stumbling block. While critical analysis of the information by independent analysts and consultants may generate some confidence, naturally the clinching assurance comes from the earlier experience of working together successfully. An offer of systematic methodology of know-how transfer and team-work can also generate confidence, specially when past experience in know-how transfer from an R&D team is limited or non-existent. Since the production team is also intimately involved in the transfer of know-how, careful selection of the production team(s) is also critical for the success of the transfer process.

One of the motivations of technology development teams is to see the fruits of their labour being utilized by the needy users. Achieving higher performance and greater reliability at costs affordable to a large body of users is well worth the painstaking and innovative efforts to improve design, fabrication and testing processes. However, without ensuring production with specified quality and in needed quantities at required schedules and at competitive costs, the development process may not progress beyond the development laboratory and reach users. As a result, the developed product may eventually go to a museum rather than to the market place. Just as a development laboratory is the most likely place for innovation and technology development, a manufacturing facility is the most suitable place to do justice to the exacting demands of production. The development laboratory and manufacturing facility thus

S. C. Gupta is in the Vikram Sarabhai Space Centre, Thiruvananthapuram 695 022, India.

form indispensable links in the innovation chain. The user forms the third link in the chain. Vigorous interaction among the three links contributes greatly to the success of the innovation cycle. What needs to be done to bring about vigorous and fruitful interaction between a development laboratory and a manufacturing facility is the subject of this paper.

This paper draws on the experience of the Vikram Sarabhai Space Centre of the Indian Space Research Organization in technology development and transfer. Identified are the features of mature and comprehensive know-how, respective responsibilities of the R&D and production teams and selection process of production team(s). A few case histories covering both successful and unsuccessful production are also presented to illustrate and clarify the issues.

Features of know-how

To enable taking up production, the production team requires the following essential details:

(i) A mature design, based on which the product has been made and has undergone successfully independent rigorous performance evaluation and service environment-endurance tests. Product should have been made in enough quantities to establish repeatability of performance within the identified tolerance band. While the design methodology does not have to be revealed, full description of materials of construction, component values and permissible tolerances, etc. is essential. A comprehensive guideline is given in ref. 1. (ii) Data on performance evaluation and environmental endurance test results. (iii) Drawings and explanatory notes using which the product can be made by a team skilled in the relevant fields, without the direct participation of the development team. Those components or processes are to be highlighted, successful realization of which requires unusually high skills of craftsmanship, meticulous quality checks and/or specialized facilities. (iv) Information on the required raw materials and components and their quality standards and sources of supply. (v) Information on quality control processes to be adopted during the various phases of production. (vi) Information on equipments for production, quality control, performance evaluation and environmental tests. (vii) Information on maintainability, servicing, essential spares, and recalibration procedures, wherever applicable. (viii) Data on consumption of energy and raw materials in the production of the product, wherever applicable. (ix) Information on effluents and their likely impact on environment and ecology with or without effluent treatment. Process and cost of effluent treatment, if any. (x) Information on hazards of any kind, if any, in the production process and effluent treatment. (xi) Information on assured demand for the product in terms of quantity, quality and pricing over a reasonable period of time or till the product is likely to become obsolete. (xii) Information on likely time by which the product will become obsolete.

The development team should be able to generate adequate data on the first five items listed above. Data on the rest may have to be generated jointly by the development and the production teams and the users, even seeking the assistance of other specialist teams. The need to generate adequate data on the items listed above, in order not to have surprises in the technical aspects during the production phase cannot be overemphasized.

Pooling of information with producers and users

Just as the production team requires certain essential information from the development teams and the users, the development team requires the following inputs from the users and the production team.

(i) Survey of the existing comparable products, their performance characteristics, quality standards, pricing and improvements desired by users. (ii) Survey of trends which may influence the onset of obsolescence of the product. (iii) Information, if any, from value engineering point of view, which may help in cost reduction without affecting performance. This could include use of alternate materials, processes, etc. (iv) Data on facilities accessible to the production team for production, inspection, performance evaluation and environment tests, so that the minimization of need for new facilities can be an objective of the development team. (v) Data on availability, quality standard, and prices of raw materials and components.

Management support

Any activity involving teams, organizations, funds and schedule needs management support. Individual and common responsibilities of the participating persons and organizations are to be spelled out in detail. Periodic reviews are to be carried out at the different managerial levels concerning technical, financial and schedule-related matters. For the sake of brevity, these are not elaborated here. However, the most critical factor concerning the attitude of all those who are responsible for implementing and reviewing the activities needs to be discussed here. A memorandum of understanding (MOU) between the participating organizations is generally entered into covering the various aspects of technical, financial and schedule-related matters. The MOU is a charter for actions under foreseeable conditions. However, when unforeseen situations arise, the MOU has always to be supplemented by the will and determination to succeed. This may call for amendments, to the MOU placing varying additional burdens on the participants. Further, the participating teams should be made to feel that the product is the outcome of their joint efforts rather than that of the development team alone. The knowledge and experience base of both the development and the production teams needs to be used in bringing out the product. Admittedly, the development team may have an edge over the production team in areas of design, technology, craftsmanship skills and performance evaluation. Likewise, the production team may have an edge over the development team in areas of production processes and equipments, sources of materials and components, costs involved in achieving quality standards, economizing on materials and energy consumption.

Technology upgradation

It is clear that passing on a product for production entails design and technology freeze. Does it mean that in this scheme of things there is no scope for improvement of design, and technology upgradation and that the innovation process is given up once the user's requirements are apparently met? Fortunately, the innovation process is continued relentlessly. However, the utilization of innovation is carried out in a qualitatively different manner. In this context, it is useful to recognize that innovation process results in a monotonic rise with time in the values of parameters representing performance, quality and productivity. The rate of rise may vary depending on achievement of major or minor breakthroughs during the innovation process. The design and technology freeze, implying the keeping of the product parameters at a fixed level, results in growth of gaps between the realizable and the frozen values of the product parameters. Upgradation of the design and technology cannot be carried out as and when the development team accomplishes them, but is carried out subsequently when the cost of implementing the upgradation is justified by the benefits of the improved product. Thus the upgradation adopted in production is like climbing up a step. This process may be repeated over a period. From the above, it is recognizable that while the product parameters undergo a continuous ramp-like growth due to innovation, they are adopted in a staircase-like manner in the production process. Over a long term the parametric levels in the innovation and production processes are nearly the same, however, at any point in time the parameters adopted for production may in general be inferior to those achieved in innovation.

Periodic quality audit

Once the production process is stabilized and the sources and quality parameters of inputs, raw materials and bought out parts are standardized, the product quality is well assured. However, small and slow changes may occur in the production process and the parameters of inputs due to a number of reasons, such as, wear of production equipment, drift in calibration of crucial measuring instruments, turn-over of critical personnel and change of suppliers of inputs. Such imperceptible changes can seriously affect the quality and yield of the product. A periodic quality audit addressing the above-mentioned parameters is therefore essential in order to maintain trouble-free production.

Some unusual aspects

The above mentioned list of items on which data has to be generated for undertaking production is fairly obvious. However, such issues as dispersal of the production process to more than one institution in order to utilize facilities wherever they may exist and thus minimize setting up of new facilities may not surface usually. In the production of advanced technology products, generally requiring large capital outlays, this issue is of major concern. If significantly expensive new facilities are essential, additional capital costs and facilities-build-up time will greatly influence the production costs and time to take the product to users. On the other hand, if the entire production process is not under one roof, smooth flow of production would require well-conceived coordination between the participating facilities. This can add to the uncertainties regarding the uninterrupted availability of the product to the users. A trade-off study to determine how much should be under one roof and rest can be dispersed may be necessary. The trade-off study may also suggest progressive variation of the dispersal management.

Indirect benefits to a production agency of undertaking production of advanced technology products with stringent quality assurance norms are not commonly recognized, although a little reflection should make the benefits obvious. The following brings out the benefits. Some examples of the quality assurance requirements peculiar to advanced technology product are:

(i) The production process is divided into a suitable number of stages and in-process stage inspection is carried out preferably by the process operators themselves. This is in contrast to the usual practice of inspection by an inspection team only at the end of the production process. Under the modified procedure, the production process is allowed to continue without interruption only if the results of stage inspections are satisfactory. Failure in stage inspection, however, calls for rework or rejection, thus avoiding infructuous processing effort and possible waste of material. This also increases the involvement and dedication of the process operators to the achievement of quality; (ii) On-line recording and analysis of production processes and inspection activities are given in ref. 2. These bring out (a) whether the production process wandered outside the specified tolerances at any stage, (b) what rework was carried out, if any, and (c) whether any performance parameters of the product are outside the specified limit.

A review of the above quality assurance data permits confident decision on the suitability of the product for the intended service by exacting users. This data also provides traceability to be able to correlate failure of the product during service with lapses, if any, during the design and production processes. Beneficial influence of such quality assurance practices on the production yield and product quality enhances the image of the production agency.

Successful production of a newly developed product has another significant, though intangible, benefit. It is the growth of mutual confidence between the development and production teams to be able to undertake challenging development and production tasks. Likewise, the user community begins to rely on such products and expects more of such successful collaborations.

Selection of production agency

The production agency plays the critical role of implementing the know-how to produce and market the new goods and services with the human and infrastructural resources accessible to them. Easy access to the needed skilled manpower and facilities for production, quality control and test and evaluation are the minimum prerequisites of a suitable production agency. If the new products and services are in line with the existing products and services of the prospective production agency, the task of successful production and marketing becomes simpler. If the production agency also has the motivation and internal capability of further value addition to the know-how, it becomes an excellent additional qualification for the selection of the production agency. An open meeting with the prospective production agencies, in which the various features of the know-how are presented by the R&D team and the capabilities of the production teams are discussed individually, can prove to be a speedy step in the selection process. Exchange of visits to the R&D laboratories and production facilities is another useful step in the selection process. Ready agreement on sharing of responsibilities during the technology transfer, implementation and marketing activities creates proper conditions for successful production.

Case histories

The concepts of linking technology development with production have been used extensively in the Indian Space Research Organization (ISRO) in general and the Vikram Sarabhai Space Centre (VSSC), in particular. Four case histories are cited here for illustration. These are concerning production of: (i) Miniature rate gyroscope; (ii) Electronics assemblies; (iii) Carbon cloth and (iv) Telemetry systems representing different fields. There are other numerous examples linking development with production in the fields of alloys, polymers, liquid fuels, large variety of mechanical components and assemblies and software which are not discussed in this paper for the sake of brevity and as the selected case histories discussed in some detail illustrate the concepts sufficiently.

Miniature rate gyroscope

VSSC had developed a highly sophisticated electromechanical instrument for measuring the speed of rotation of solid bodies, undergoing complex motion, and producing a proportional electrical signal with stringently specified precision and accuracy. The instrument, operating on the principle of conservation of angular momentum and interaction of gyroscopic torques, is known as a rate gyroscope. The main sub-assemblies comprising the gyroscope are a spin motor usually running at 24000 rpm, a torsion bar, a microsyn, a flotation system and a pivot-jewel assembly. The subassemblies have a total of 16 high precision fabricated parts and a number of bought-out parts. The physical size of the instrument puts it in the miniature category.

During the development phase, the VSSC team evolved the geometry and the material for the parts, the processes for machining, fabrication and heat treatment, the assembly procedures and performance checks on the subassemblies, the process tools required during the production and assembly and procedure for assembly and performance evaluation. The development team also evolved the detailed quality assurance procedures concerning raw materials, bought-out parts and production and assembly process. After achieving the required performance of the gyroscope consistently over a number of units, the design, fabrication, assembly, performance evaluation and quality assurance information, as listed earlier, was documented as a Technology Transfer Document. Then, the search for a suitable production agency was made. A facility which was producing instruments based on comparable technologies under licence from a number of foreign manufacturers was located. After discussing with the production facility and agreeing on the terms of the order and the minimum significant size of the order, a two-phase production order was placed with provision for total buy-back. In the first phase, only the full sets of the 16 fabricated parts were to be produced. In the second phase, which was to commence only after completing successfully the first phase, the complete instrument was to be produced. In order to reduce the uncertainties on schedule, quality and cost all special raw materials and bought-out parts were supplied by VSSC.

When the production agency commenced the fabrication of parts, difficulties were experienced in realizing the stringent geometrical tolerances on some of the parts. Difficulties were also experienced in achieving quality standards in soldering electrical connections, miniature coil winding and inspection of precision engineered parts. Some difficulties also arose because the production agency was following the method of doing inspection at the completion of the fabrication and machine shop work. Stage inspection was not in vogue. Because of this practice, the shop floor technicians were not issued the precision gauges needed for stage inspection. As a result, the non-conformance with the specified geometrical tolerances was detected only at the completion of the fabrication and machine shop work. Consequently, the yield was poor for even those parts which the production agency could manage to produce in the early trials. In the management level review, these difficulties were brought up and the following remedial action were identified for implementation:

(i) Training-cum-demonstration of fabrication, machining, soldering, miniature coil winding and stage inspection of the difficult-to-produce parts to the technicians, inspectors and supervisors of the production facility at the development laboratory. If necessary, repeat the demonstration of producibility at the production agency using facilities available there by the development laboratory technicians. (ii) Introduction of stage inspection at the production agency, entailing increase in the scope of responsibility of the production technicians and for this purpose equipping them with the required precision gauges.

During the subsequent management level reviews, while significant improvement in the yield of most of the parts was observed, as a result of the above mentioned measures, a few parts continued to elude satisfactory production. In order to solve this problem and to improve the yield further, the production agency decided to set up a separate Cell in the facility to fabricate and machine the gyro parts and to equip the Cell with a few special machine tools recommended by the VSSC development team. On registering satisfactory progress on the first phase, the second phase was taken up concurrently with the first phase, as a modification of the earlier plan.

The gyroscopes coming from this production arrangement have been available to the entire launch vehicle programme of ISRO from SLV-3, ASLV to PSLV and have never been cause of the failure of the launch vehicle missions. All through the working together, the development and production teams maintained the spirit of searching for solutions rather than alibis for failures and of strict adherence to systematic quality assurance procedures.

Electronics assemblies

The space launch vehicles and satellites have on-board a large number of special electronics assemblies for performing the functions of measurement, signal processing, data acquisition, telemetry, trajectography, telecommand, attitude control, electric power conditioning, flight sequencing, etc. These assemblies span the frequency spectrum from d.c. to several Gigahertz and are of both analog and digital type. The electronics components used in them are of high reliability standard and the workmanship standards on components preparation, mounting, soldering, harness preparation are of equally high reliability standard, so that the assembly can successfully withstand the hostile environment during launch and in-orbit operation in space. The quality and workmanship standards are given in refs 3–7. For the assemblies to deliver performance in a narrow tolerance band in terms of gain, frequency and voltage stability, over a wide temperature environment, the component values need to be in correspondingly specified narrow bands. Tuning, performance checking and quality inspection at various stages of the production are in general indispensable, in order to get satisfactory yield from the production.

After the satisfactory completion of the design and development process at VSSC, production documents were prepared incorporating the information listed earlier in this paper. A number of suitable production agencies were identified and contracted with the production of the electronics assemblies used in the ASLV, PSLV and the Rohini Sounding Rockets. Although the technicians, inspectors and supervisors at the production agencies were reasonably well skilled, it was found necessary to give them additional training in the techniques of making high reliability electrical connections, spotting sub-standard connections and repairing the sub-standard connections while maintaining the quality standards. It was also found necessary to introduce stage inspection during the production of printed circuit boards and the final assembly operations.

During the periodic management level reviews, the spirit of problem solving in order to achieve the goals was maintained by the development and production teams.

Currently, about 38 varieties of electronics assemblies, ranging from the simple signal conditioning units to complex guidance and control computers, are being produced in industry. The electronics assemblies so produced have given faultless performance in the ASLV, PSLV and RSR flights. A few of these electronics sub-assemblies are also used completely satisfactorily in the IRS-1A, 1B, 1C and INSAT-2A, 2B, 2C satellites providing in-orbit services.

Carbon cloth

The nozzle of the solid propellant rocket motors is lined with layers of phenolic-resin impregnated carbon cloth. The basic function of these layers is to maintain the internal dimensions and the strength of the metallic structures of the nozzles under supersonic gaseous flow at temperature higher than 2000°C and the flow lasting up to two minutes. The carbon cloth is produced by carbonizing a special grade of rayon cloth, having a particular type of weave pattern. The carbonization is a multi-stage process and is to be carried out in furnaces with special liquid medium and gaseous environment and at different temperatures going up to about 1000°C. The carbon cloth is about 1 m wide and in continuous lengths of not less than 50 m. Specifications of the cloth in respect of carbon and sodium contents, breakstrength in warp and fill directions, thickness and mass per unit area have stringent tolerances. There are only a handful of qualified producers in the whole world of this grade of the carbon cloth and the technology of production is a closely guarded commercial and strategic secret.

VSSC had developed *de novo* the carbon cloth production process in 40 mm width and 500 mm length size and prepared a detailed document giving the desired rayon cloth characteristics, the carbonization process and quality control procedures. The production agency, identified through a competitive selection process, was to scale up the carbonization process and adopt a batch or continuous process to produce the carbon cloth with the specified characteristics. The selected production agency turned out to be a brand new venture, entailing the *de novo* design and procurement of the process equipments and design and construction of the plant buildings. VSSC organized for them a technology demonstration programme in order to (i) confirm the reproducibility of the lab scale carbon cloth processing technology, (ii) familiarize with the processing testing and evaluation techniques, and (iii) enable them to have an independent verification of the technologies under transfer. During the selection of the process equipments and the scaling up exercises the development team provided specialist advice. The initial technical difficulties faced in commissioning the process equipments, evolving the scaled up process, analysis of cloth samples, improving the yield were painstakingly reviewed and overcome. The production agency also came up with some useful innovative ideas. The carbon cloth is now being produced regularly, fully conforming to the specified quality standards and used in the solid propellant rocket motors of VSSC.

Telemetry systems

ISRO had developed a complete set of telemetry system for monitoring the inflight performance of sounding rockets and satellite launch vehicles and the in-orbit health parameters of satellites. Both the on-board and ground segments and both analog and digital versions were developed and used extensively in over hundred missions of Rohini Sounding Rockets, SLV-3 vehicle, ARYABHATA and BHASKARA satellites. The performance of the telemetry system was invariably spot-less and helped ISRO extract valuable information from these missions. On the basis of this performance record a specially configured telemetry system was designed, built and supplied to Hindustan Aeronautics Ltd for use in their new aircraft developments. Encouraged by these achievements, ISRO tried to interest Indian industry to undertake production of the telemetry system for application to the massive oil and gas pipeline projects in the country. A workshop on Application of Telemetry in Industry was held followed by an ISRO–industry meet on the theme. In spite of the proper credentials of ISRO and strenuous efforts to familiarize industry with the capabilities and the potential market for the telemetry system, imported know-how won the pipeline application. Apprehending similar preference in other applications, industry did not select the know-how from ISRO. Thus, this constitutes a case of unsuccessful production for non-space applications.

1. 'Design Review Requirements for ISRO Projects', ISRO-PAS-200, Jan. 1982.
2. 'Failure Reporting, Analysis and Corrective Action Procedures', ISRO-PAS-201, May 1982.
3. 'Workmanship Standards for Fabrication of Electronic Packages', ISRO-PAX-300, December 1983.
4. 'Design Requirements for Printed Circuit Board Layout and Artwork', ISRO-PAX-301, September 1983.
5. 'Test Specification for Printed Circuit Boards', ISRO-PAX-302, November 1985.
6. 'Design Requirement for Multilayer Printed Circuit Board Layout and Art Work', ISRO-PAX-303 (1), December 1987.
7. 'Screening Requirements for Electronics Parts', ISRO-PAS-204, December 1984.

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