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Technology Commercialization in Advanced Materials Sector: Indian Context

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This study is aimed at developing insights into the Technology Value Chain (TVC) of advanced materials-based technologies using a scenario in which technology has been transferred by a Research and Technology Organization (RTO) to a Small and Medium Enterprise (SME) in the Indian context. A Conceptual Theoretical Model (CTM) using constructs from existing TVC models is used as a basis for the case study described in this paper. This model is refined using actual evidence from an Indian RTO - the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), Hyderabad. The TVC of ARCI's proprietary Detonation Spray Coating (DSC) technology is used to expand upon the CTM as well as to provide new insights wherever possible. The TVC adopted for DSC includes technology incubation and proof of concept in advance of transferring the technology. These strategies, aided by government funding of the technology recipient companies, were observed to play an important role in successful commercialization.

Keywords: Technology commercialization, technology value chain, advanced materials technologies, detonation spray coating

Technology commercialization is a key factor in determining corporate competitiveness and national growth in a knowledge economy. It is a complex process requiring a variety of skills including product development, technical and market feasibility analysis, intellectual property acquisition, venture funding and much more. The objective of the present study is to develop an improved understanding of the Advanced Materials Technology (AMT) value chain in India in a scenario in which technology is being transferred by a Research and Technology Organization (RTO) to an industrial organization, generally a Small and Medium Enterprise (SME). Challenges for TVC emerge from various sources like industry sector[1,2] technology transfer from RTO to SMEs, and the ecosystem of the nation in which commercialization is being undertaken. It is widely accepted that industry sector is a key factor for the TVC. *Advanced* materials encompass traditional materials that have been improved as well as new materials recently invented.[3] Though commercialization of AMTs offers opportunities for value creation in several industry segments, there are also significant barriers that need to be surmounted. Due to the above challenges, management of AMT value chain requires special attention especially in a scenario in which technology is being transferred from an RTO to SMEs.

The primary questions that have guided this paper are: (1) What roadmap should be adopted for AMT commercialization process triggered by an RTO in Indian context? (2) What are the crucial decision points during the whole process and why are these decisions taken? The paper includes a comprehensive literature survey to identify gaps in the existing models by assessing their suitability to address relevant challenges. Then, a conceptual model is proposed. Paper further provides a rationale for case research design, probes an AMT commercialization case study to fill the gaps identified in the existing literature.

Literature Review

Technology commercialization is a process of gathering ideas, enhancing their value with complementary knowledge, developing and manufacturing saleable goods, and selling such goods in marketplace.[4] Hence, this process encompasses all activities from idea generation, product design, prototype testing and manufacturing, to marketing.

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Previous research has attempted to identify challenges and models to enhance the success rate of commercialization. The next three sections mention the challenges, commercialization models and proposed conceptual model.

Challenges

There are substantial challenges associated with the commercialization of AMTs transferred from RTO to SMEs in the Indian context. These typically originate from three major sources: the nature of the AMT sector itself, the RTO to SME technology transfer process, and the Indian eco-system. Constituent dimensions associated with the challenges are assigned codes to facilitate subsequent analysis. AMT sector challenges pertain to the identification of potentially relevant opportunities for SMEs (code: T1)[3,5] up scaling of the technology (code: T2)[3,5,6,7] competition from other materials (code: T3),[8] dealing with technological obsolescence (code: T4),[6] prioritizing possible applications (code : T5)[7,9,20,35] estimating market size (code: T6)[7,10,11], user needs which can be reason for switch to another technology (code: T7).[7,11,34,35] RTO to SME technology transfer challenges are associated with the need of forging multiple alliances to demonstrate a technology (code: TT1)[3,6,7,11-15] preparing a business case for an unproven technology (code: TT2),[16,17] transitioning technology-push innovations to market-pull innovations (code: TT3),[3,15,18] lack of technology absorption capability with SMEs (code : TT4).[5,18] Challenges associated with the Indian ecosystem include accessing capital for research and technology projects ongoing at RTOs (code: E1),[12] availability of capital for commercialization of manufacturing technologies by SMEs (code: E2);[19-22] lack of capability in SMEs about IP management and alliance making (code: E3);[22-25] non-availability of required infrastructure for nurturing of start-ups and testing of products manufactured by these start-ups (code: E4).[20,21,22,26,27,28]

Commercialization Models

In recent times, several technology commercialization processes have been proposed and authors have attempted to categorize them as linear, iterative and conceptual models. These models have been assessed with respect to their capability to address above 15 challenges (T1 to T7, TT1 to TT4, E1 to E4). Generally, linear models move in a step-by-step manner and lack feedback mechanism, iterative models take into account feedback from relevant stakeholders to implement required corrective actions, and conceptual models address major factors responsible for successful commercialization. Some prominent models belonging to the various categories are reflected in the brief review provided below.

Linear Models

Linear models for technology value chain, generally, initiate with a sequence of design and development and end with transfer of a new product or process via manufacturing, distribution, sales, and service.[29] Several of these models have apparent limitations and are clearly inappropriate to deal with the challenges associated with commercialization of AMTs. Goldsmith model (1999)[30] lacks flexibility regarding feedback. De Saram model (2001)[31] describes the commercialization approach adopted by the National Engineering Research and Development Centre of Sri Lanka. This model skips activities dealing with market sensitization, demonstration and promotion of a technology in the market place. Narayanan model (2001)[32] focuses, mainly on funding requirements for different stages of a project, while it does not address issues dealing with the methodology for selecting a project or the modus operandi for transitioning from one stage to another. Kotelnikov model (2002)[33] involves 5-stage R&D commercialization steps, but suffers from lack of formal feedback mechanism. Andrew and Sirkin model (2006)[34] addresses three phases of idea generation, commercialization and realization, and is not elaborate. Excell Partners (2007)[35] recommend the need of invention disclosure during pre-seed stage and suggest that sustainability of innovations in the marketplace by conducting lab prototype tests by utilizing seed funding. Production activities can be launched by using early-stage funding. This model views technology commercialization from the viewpoint of start-up companies' interested in innovation commercialization and not suited to the RTOs interested in commercializing their technologies. Warner model (2008)[36] does not provide details of all the stages that lead to innovation commercialization. Several crucial steps from proof of concept to sustainable business model are not discussed in the model.

Iterative Models

In iterative models, innovation teams usually focus on a collective pool of knowledge, secure and manage the resources needed to generate the innovation, and utilize feedback from relevant stakeholders to take corrective actions, if necessary, till completion of commercialization. According to Rothwell and Zegveld (1985),[37] commercialization is an integral component of the innovation process. Constituent phases of the model are ideation, development, prototype production, manufacturing, commercialization, and marketing. The Stage-Gate model proposed by Cooper (1988)[16] provides a conceptual and operational map for managing new product/process development (NPD) processes, but does not provide a detailed elaboration of technology development and transition from technology to product. Jolly model (1997)[23] captures several features pertinent to materials commercialization by using relevant case studies, mainly from developed economies. Model divides commercialization process in five sub-processes (techno-market insight, incubation, demonstration, adoption, and sustaining commercialization) and four bridging steps aimed at mobilization of necessary support (peers and potential beneficiaries, resources for demonstration, market constituents, and complementary assets). However, refinements are necessary to accommodate specific features of commercialization occurring due to transfer of AMTs from public funded RTOs in Indian context. According to Allen (2002),[38] the commercialization process involves sub-processes of invention and innovation, opportunity recognition, IP assets' protection, product development, business concept testing, business plan preparation, and the business launch. Several activities are carried out within each sub-process. Kathleen model (2002)[17] addresses phases like inventing and innovating, recognizing opportunity and protecting Intellectual Property Rights (IPRs), developing new products etc. Model does not sufficiently address complex issues associated with materials technologies development, demonstration, transfer and commercialization. Shaista, Tomasz & Bernstein (2006)[39] discusses activities dealing with financing needs and alliance formation. Though model has been proposed for biotech sector, useful suggestions for envisaged model have been provided. Goyal & Menke model (2006)[40] links commercialization process' stages to corporate goals of an organization. This model does not provide advisory for transfer of technology from RTO to industry.

In addition to the above, another model proposed by Sun *et.al* (2008)[41] addresses critical factors responsible for successful technology commercialization without paying attention to sequencing of steps and therefore, cannot be used for holistic understanding of sub-processes associated with commercialization of AMTs. This model attempts to describe the factors (concerning technology, organization, customers, government regulations, academic support etc.) affecting the commercialization process. This model does not use inputs from feedback mechanisms for necessary corrective actions while taking a technology to marketplace, and hence may not be used to develop insights for the AMTs commercialization process triggered by an RTO in India. We find that no single study has pointed out dimensions that address all the challenges.

Proposed Conceptual Theoretical Model

The Conceptual Theoretical Model (CTM) depicted in Figure 1 emerges from the literature survey, and addresses the sub-processes typically associated with commercialization of AMTs in a scenario in which technology has been transferred by an RTO to SMEs

It is apparent that the extant literature lacks a framework that can be adopted by publicly-funded RTOs after the viability of their technology has been demonstrated. However, there has been much discussion in the literature about the commercialization process adopted by companies in order to transition in-house technology/know-how to the marketplace. The sub-processes identified in Fig. 1 need to be further elucidated due to their inability to address the RTO-SME interaction for commercializing AMTs in the Indian context. The approach of identifying sub-processes and constituent dimensions is consistent with Eisenhardt (1989)[42] advice of choosing constructs from research questions and from extant literature. Accordingly, the sub-processes and nine constituent dimensions (i.e. T1,T2,T3,T5,T6,T7,TT1,TT3,E1) of CTM that require further probing are indicated in Table 1:

The remaining six dimensions (T4, TT2, TT4, E2, E3 and E4) have been discussed previously and are not mentioned in Table 1 due to their relevance for

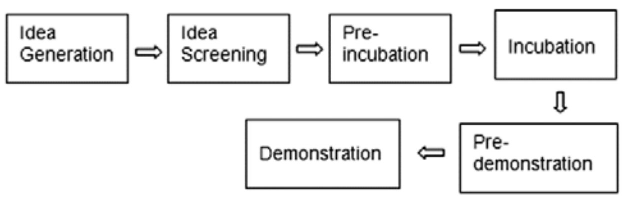

Fig. 1 — Conceptual Theoretical Model

Table 1 — Sub-processes and dimensions to be probed further

S. No.	Sub-process	Dimensions to be further probed (codes)
1	Idea generation	T1, T3
2	Idea screening	T7
3	Pre-incubation	T5, T6, TT1, E1
4.	Incubation	T2, T3
5	Pre-demonstration	T6,TT1, TT3
6	Demonstration	T2,T3

post-demonstration sub-processes. The CTM does not address post-demonstration sub-processes.

Method and Research Design

Choice of Case-Study Methodology

A longitudinal case study approach an appropriate for this paper for the following reasons: First, it is a preferred methodology compared to approaches such as experimental, survey, archival analysis, and historical when "what", "how" or "why" questions are being posed, when the researcher has little control over events, and when the focus is on a contemporary phenomenon in a real-life context.[43] Second, case studies are useful in situations in which the intervention has occurred and the effect of that intervention has to be assessed. Third, the case study method facilitates holistic and deeper understanding of a phenomenon[44] while other research approaches (such as survey and statistical) provide an average view. Fourth, the case study extends and enriches a theory by accommodating the relevant features of available theor.[43] Finally, case studies allow the triangulation of data from multiple sources.

Operationalization

Good quality case research design necessitates construct validity.[45] Relevant real-life case can be used to refine a CTM[46] and to address complex process of TVC since it is not possible to quantify constituent sub-processes and dimensions of the CTM for TVC in the advanced materials sector. A detailed study of the DSC TVC would likely provide hitherto unavailable information that is unique in the national context.

A case study should be investigated based on actions rather than on an individual or a group of individuals.[47] Keeping this in view, the initial Discussion Guide (DG), containing open ended questions based on the studies conducted by previous scholars, was framed to collect relevant information on potentially important dimensions of the DSC TVC.[48,49] Queries included in the initial DG, derived from research questions as well as from the CTM, were used as a pilot while conducting first interviews for collecting data on DSC TVC. Interviews were conducted with two key officials closely associated with the TVC. Revisions were made in the initial DG based on the experience of collecting initial data related to DSC TVC. Irrelevant questions were excluded from the DG and some relevant questions were added based on the feedback from pilot. The revised DG (attached as Appendix I) was then used to recollect data about DSC TVC. Such a DG helped to elicit details from informants in a way in which participants deemed them appropriate. The above research protocol facilitates structured examination of a case and allows linking of findings from a real-life case with the dimensions of the CTM.[50]

Case Selection

Researchers in the field of case study such as Yin (2003)[50], Stake (1995)[51] and Feagin (1991)[52] have asserted that case study research should not be treated as sampling research. Rather, a selected case should maximize the understanding of a process. Yin (1994)[43] recommends the use of single cases to add insights to a theoretical framework wherein a single case is unique or revelatory since information about such a case is not otherwise accessible. For instance, Levy (1998)[53] used a single-case design for the study relating to the pace of acquisition of the information technology at institutions of higher education.

Single unit of analysis, TVC of the DSC technology, is being used in this paper to provide insights to the meager literature on the subject and to enrich the CTM. This case brings unique and revelatory insights on a technology that was developed/demonstrated by a government funded RTO and commercialized by SMEs for the first time in India. A major step in designing and conducting a single case is defining the unit of analysis (For example: DSC technology). The DSC technology, an attractive thermal spray variant for depositing high quality wear resistant coatings on components from industry segments like aerospace, automotive, power, mining etc.[54,55] transferred by ARCI to four SMEs.

Data Collection

The present study used multiple sources including responses received during interviews conducted with open-ended DG, direct observation and the information available in documents like annual performance reports. Dane (1990),[56] Koners and Goffin (2007),[49] Miles and Huberman (1994),[45]and

Yin (1994)[43] suggest multiple sources of evidence to ensure internal validity and the reliability of the case study research. Interviewees answered questions mainly to elaborate the RTO's role in the TVC. Investigations were attempted to assess the impact of crucial decision points on the commercialization outcome. In all, 6 rounds of interviews were conducted with key officials/scientists involved in value addition activities associated with the DSC case. The major informants included two senior scientists from ARCI, Hyderabad (India). Interviews lasted from 60 to 180 minutes. The concerned scientists were provided the DG before the scheduled interview so that they could prepare themselves for the interview. Clarifications, if any, on the contents of the DG were provided to the informants. Notes were made to record discussions in the interviews. Collected data was triangulated with evidence from the documentation and the direct observation. The sequence of events in the case was prepared chronologically after collecting data. Case details were submitted to the interviewees, who were asked to add any other crucial aspects that could not be gathered during interviews. Though three of the four authors were also actively involved with different aspects of the TVC, extreme care has been taken so that their bias does not affect description and interpretation of the case. This has been ensured through triangulation of the information through multiple sources. Summary of the case has been provided in the following section. Companies' names are not disclosed in the case summary due to confidentiality.

Case Description and Analysis

The process adopted by an Indian RTO - ARCI - for transfer and commercialization of its DSC technology has been described below. The section has two parts: case description and Within Case Analysis (WCA); and case insights.

Case Description

The DSC technology was identified by an ARCI team in 1990 for development due to its demand for certain strategic applications as well as in consideration of the possibility of its commercial exploitation in India. A DSC system was acquired by ARCI from a partner institute - Institute for Problems in Materials Science (IPMS) Ukraine - in the erstwhile Soviet Union to understand underlying scientific principles. The partner institute had been working on the DSC technology since the 1960s and had developed the technology almost concurrently with Praxair Surface Technologies - a multinational corporation. During its initial development efforts, the ARCI teams focused on demonstrating that the properties of detonation sprayed coatings were comparable to those reported in the scant literature available on the DSC technology and vastly superior to other competing coating techniques. ARCI embarked on validation studies for selected aero-engine components identified by the aeronautics company. Choosing appropriate applications is a key to derive value from a technology [57]. In this case, the components chosen for initial validations were those on which detonation spray coatings were already being applied abroad and success with such critical aero-engine components was bound to generate confidence in other less-demanding users.

By August 1992, the detonation sprayed coatings on aero-engine components had successfully completed stipulated validation tests and statutory clearances for production. DSC equipment in operation, DSC equipment and coated aero-engine component are shown in Figures 2, 3 and 4. Over 13,000 parts had been coated by ARCI since the coatings went into production in January 1993 and successfully field-tested in nearly 150 engines.[58] In addition, wear and corrosion resistant coatings were also successfully demonstrated for suitably identified high pressure pump components. During 1993-94 links were forged with fabricators and suppliers of

Fig. 2 — DSC equipment in Operation

Fig 3 — DSC equipment

infrastructural facilities like pre-coating, post-coating and job-handling for making up scaled DSC facility. ARCI did not face any reaction from incumbent companies providing similar coating solutions probably due to the focus of these companies on other relatively bigger markets. From 1994 onwards ARCI embarked on a job-work mode of operation thereby making its DSC facilities easily accessible to strategic, public and private (such as textiles, automotive, power, and cable manufacturing) sectors. Such coated components are shown in Figures 5 and 6. By making trade-offs between coating features and users' needs, the spectrum of coatings applied by the DSC route at ARCI was diversified to include metal and metal-oxide coatings apart from the carbides. Several of these efforts contributed to import substitution. In each case, the coating quality was optimized by adopting a systematic statistical design of experiments methodology involving comprehensive evaluation of the effects of different parameters on relevant coating characteristics and the assessment of coating performance using specially designed test rigs.

Fig. 4 — Coated turbine blade (aero-engine component)

Fig. 5 — Coated stepped cone pulleys

Fig. 6 — Coated spindle valves for power generating steam turbines

Properties of detonation spray coatings produced at ARCI were benchmarked with the detonation spray coatings supplied by a leading global player[58].In addition, ARCI also benchmarked the capabilities of its DSC technology with other commercially popular, and often competing, coating technologies like High Velocity Oxy-Fuel (HVOF) and Atmospheric Plasma Spray (APS) systems. At this stage, techno-commercial attractiveness of DSC technology was evident due to its ability to deposit a large variety of coatings for different user segments, virtually trouble-free operation during prolonged use, ease of handling by trained operators and low operational costs. This only served to further reinforce the original conviction that the DSC technology was tailor-made for commercialization in India. As a consequence, ARCI decided to indigenize the DSC technology in association with the foreign partner institute - IPMS Ukraine - and signed an Agreement in April 1997 with the IPMS to collaboratively fabricate DSC systems. Accordingly, fabrication of DSC units was completed and the units were made available in for acquisition by the private sector.

A workshop on business and market opportunities in surface engineering was organized by ARCI in January 1999 to sensitize industry about the potential of surface engineering technologies in general, and DSC technology in particular. Other promotional initiatives were also taken by ARCI to enhance awareness of DSC technology. Based on ARCI's assessment of the commercial potential of the DSC technology, a conscious decision was taken to transfer the technology to four companies in India (Table 2) on a regionally exclusive basis (a) to limit the number of DSC units based on the perceived market size, and (b) to create conditions for long-term presence of DSC technology-based businesses in market by nurturing their growth in each region.

Low-cost loans from Indian government agencies like Technology Information, Forecasting and Assessment Council (TIFAC) and Technology Development Board (TDB) also played a crucial role

Table 2 — DSC Technology receiving companies (TRCs)

Month and year of signing agreement	Technology receiving companies	City	Region	Subsidized loan (partial funding) support agency
May1999	TRC1	Chennai	South	TIFAC
January2000	TRC2	Hyderabad	Central	TIFAC
January2000	TRC3	Mumbai	West	TDB
January 2004	TRC4	NOIDA	North	TDB

Idea Generation (1990)

↓

Identified by ARCI team due to immediate need for strategic applications and potential of industrial applications. DSC technology was unique in Indian context, at that time.

Idea Screening (1990)

↓

ARCI's leadership supported the technology development program due to its potential to replace imported coated products

Pre - Development (1991)

↓

After understanding process fundamentals, DSC technology was validated on critical aero-engine component. This was expected to generate interest of other civilian segments

Prototyping (1992-94)

↓

After understanding process fundamentals, DSC technology was validated on critical aero-engine component. This was expected to generate interest of other civilian segments

Pre-Demonstration (1994-95)

↓

ARCI tied-up with few companies, which were interested in using detonation spray coated products

Demonstration (1995-98)

↓

Applications of DSC coatings were proved on real life components of multiple sectors (textiles, automotive, power etc.) using variety of coating compositions

New Sub-process 1

↓

Workshop in January 1999 was organized to sensitize industry. This led to regionally exclusive technology transfer to three companies during May 1999 -January 2000, to fourth company in January 2004

New Sub-process 2

↓

ARCI provided guidance to TRCs for accessing subsidized finance, for establishing commercial facility, troubleshooting, applications and market development

New Sub-process 3

↓

ARCI's support to TRCs continues by improving different aspects of technology and finding new applications avenues

Fig. 7 — DSC commercialization — Process map

during the fledgling years of the DSC business. The importance of governmental financial support for technology commercialization has also been highlighted by Caerteling *et.al* (2008)[57] and Lerner (1999).[59] Though demand for DSCs was created by ARCI in multiple potential segments like aerospace, textiles, pumps, strategic, and energy, Technology Receiving Companies (TRCs) have been working to further capture untapped markets. To cater to the increased business volume generated as a result of encouraging market response, TRC2 procured a second DSC unit from ARCI during the year 2005-06. Apart from support for commercialization activities undertaken by the TRCs; ARCI has continuously been engaged in improving different aspects of technology, and finding new application avenues.

Within-Case Analysis

Findings were analyzed to elucidate the entire process. Data analysis is shown in Tables 3 to 11. The nine challenges identified in Table 1 have been addressed using six sub-processes of CTM. In addition we have captured new sub-processes that were found in the case. The three new sub-processes

Table 3 — Idea generation (Challenges : T1, T3 as per Table 1)

Insights gained from case findings (code)	Linkage to existing models and the case
National priority (DSC1)	Finding from the case
Business opportunity (DSC2)	Consistent with the 5 iterative models (Rothwell & Zegveld,[37] Cooper,[16] Jolly,[6] Allen,[38] Goyal & Menke[40] models)
Import substitution (DSC3)	Finding from the case
Potential to benefit sufficiently large segments (DSC4)	Consistent with the 5 iterative models (Rothwell & Zegveld,[37] Cooper,[16] Jolly,[6] Allen,[38] Goyal & Menke[40] models)
Idea's fit with mission/mandate/goals of the RTO (DSC5)	Consistent with the Goyal and Menke model[40]
Conduct literature , including publications and patents, survey (DSC6)	Consistent with the Kathleen[17] and Jolly[6] models
Assess partnership needs (DSC7)	Consistent with the Kathleen[17] and Jolly[6] models
Formulate proposal (DSC8)	Consistent with the Kathleen[17], Jolly[6] and Cooper [16] models

Table 4 — Idea screening (Challenge : T7 as per Table 1)

Insights gained from case findings (code)	Linkage to existing models and the case
Identifying addressable problems (DSC9)	Consistent with the Kathleen,[17] Jolly[6] and Cooper [16] models
Prepare idea implementation roadmap (DSC10)	Finding from the case
Seek commitment of RTO's leadership (DSC11)	Consistent with the Goyal and Menke Model[40]
Seek funding , whether internal or external (DSC12)	Finding from the case

Table 5 — Pre-incubation (Challenges : T5, T6, TT1, E1 as per Table 1)

Insights (code)	Linkage to existing models and the case
Forge mutually beneficial partnerships with scientific institutes and industry (DSC13)	Consistent with the Jolly[6] model
Conduct laboratory experiments. Statistical design of experiments was appropriate since effect of large number of variables was to be understood (DSC14)	Consistent with the Jolly[6] and Cooper[16] models
Take judicious decision with respect to IP (DSC15)	Consistent with the Kathleen[17], Jolly[6] and Cooper[16] models
Publish and present non-patentable research output (DSC16)	Consistent with the Jolly[6] model

Table 6 — Incubation (Challenges : T2, T3 as per Table 1)

Insights (code)	Linkage to existing models and the case
Optimize DSC process with cost-effective coating powders of consistent availability (DSC17)	Consistent with the 5 iterative Models (Rothwell & Zegveld,[37] Cooper,[16] Jolly,[6] Allen,[38] Goyal & Menke[40] models)
Prepare prototypes (DSC18)	Consistent with the 5 iterative Models (Rothwell & Zegveld,[37] Cooper,[16] Jolly,[6] Allen,[38] Goyal & Menke[40] models)
Shortlist possible test sites and test prototypes (DSC19)	Consistent with the Kathleen[17] and Jolly[6] models
Analyze feedback (DSC20)	Consistent with the Kathleen[17] and Jolly[6] models

Table 7 — Pre-demonstration
(Challenges : T6,TT1, TT3 as per Table 1)

Insights (code)	Linkage to existing models and the case
- Assess RTO's resources and capabilities to explore potentially beneficial tie-ups (DSC21)	Consistent with the Jolly[6] model
- Prioritize applications in view of the available capability, potential market size, and value addition (DSC22)	Consistent with the Jolly[6] model

Table 8 — Demonstration (Challenges : T2, T3 as per Table 1)

Insights (code)	Linkage with existing models and the case
Pilot scale-up (DSC23) Repeatedly produce at pilot/semi-commercial scale for chosen application (DSC24)	Evidence of the case regarding pilot scale-up and repeated production extends the related dimensions by Jolly[6] and Cooper[16] Models
Validate product, process by customer acceptance and establishing feasibility (DSC25)	Consistent with the Kathleen[17], Jolly[6] and Cooper[16] Models
Take IP decisions judiciously (DSC26)	Consistent with the Kathleen[17], Jolly[6] and Cooper[16] Models
Consider technology, market, environmental and regulatory factors together (DSC27)	Consistent with the related dimension of Kathleen[17] and Jolly[6] Models
Prepare technology document (DSC28)	Finding from the case

Table 9 — New Sub-process 1

Findings	Insights (code)	Comments	Emerging Sub-process 1
- Business Opportunity Workshop organized in January 1999 to sensitize industry - Presentations in conferences/seminars - Transfer to 4 TRCs - Regionally exclusive transfer. - ARCI provided relevant inputs to TRCs in making techno-commercial feasibility reports	Identify possible technology receivers, if not associated during earlier steps (DSC 29)	Finding from the case	Technology Transfer
	Understand the process by which TRCs in-license an external technology (DSC30)	Finding from the case	
	Sign technology transfer agreement (DSC31)	Consistent with the Kathleen[17] model	
	Provide inputs for preparing Business Plan (DSC32)	Modifies dimension by Kathleeen[17], Jolly[6] and Cooper[16] models for context of RTO - SME interaction. It is important to note that dimensions of these three models were given for different contexts.	

Table 10 — New Sub-process 2

Findings	Insights (code)	Comments	Emerging Sub-process 2
- Technology absorption was facilitated by providing technology document, training to TRCs staff, and by providing assistance in establishing production facility, troubleshooting - Advice to TRCs on market expansion. For this, R & D team accompanied TRCs to educate the end-users - Advice on compliance with regulatory, safety, health and environmental norms - Guidance by ARCI to receive subsidized finance - Markets generated by ARCI was shifted to TRCs keeping in view the location of each TRC' facility. - One of the TRCs was provided incubation facility	Provide technology document (DSC33)	Finding from the case	Support for initial production
	Assist TRCs in establishing production facility (DSC34)	Finding from the case	
	Training for TRC's staff (DSC35)	Consistent with the Kathleen[17] Model	
	Advice to TRCs on product features improvement, cost cutting, troubleshooting (DSC36)	Consistent with the dimension of Jolly[6] Model	
	Advice to TRCs on operational efficiency improvement (DSC37)	Finding from the case	
	Advice to TRCs on segments to be targeted , positioning (DSC38)	Consistent with the related dimensions of Jolly[6] model	
	Advice to TRCs on educating the target segments (DSC39)	Finding from the case	
	Advice to TRCs on tie-ups for skills/infrastructure/funding (DSC40)	Finding from the case	

Table 11 — New Sub-process 3

Findings	Insights (code)	Comments	Emerging Sub-process 3
- Work at ARCI has been ongoing to upgrade existing features of existing equipment and resultant coatings. - TRCs are also provided support to develop challenging applications. - TRCs are also guided on possible threats by emergence of newer technologies, and emerging competitions.	Continue working on technology to improve upon process, product to strengthen the technology (DSC41)	Consistent with the related dimensions of Jolly[6] model	Support for Long-term Sustenance
	Start working on next generation of technology and give preference to existing TRCs for transfer (DSC42)	Finding from the case	
	Support TRCs by providing technical assistance in capturing newer markets with existing/evolving application developments (DSC43)	Consistent with the related dimensions of Jolly[6] model	
	Advice to TRCs on possible diversification and expansion opportunities (DSC44)	Finding from the case	
	Monitor emerging competitions (DSC45)	Consistent with the related dimensions of Jolly[6] model	

observed during the Within-Case Analysis (WCA) are shown in Tables 9 to 11. Each Table describes how the challenges mentioned in Table 1 are addressed. Insights generated from the analysis are coded to facilitate further analysis.

WCA of DSC technology commercialization, shown in Tables 3 to 11, has helped in augmenting the CTM's six sub-processes from Idea Generation to Demonstration. Analysis results in identification of three new sub-processes. Newly identified sub-processes include activities that can be named as "Technology Transfer" from a public-funded Indian RTO to SMEs, "Support to TRCs for Initial Production", and "Support for Long-term Sustenance". This analysis points out a rationale for a new model/framework to address the commercialization of AMTs involving transfer of technology from an RTO to SMEs in India. The next section uses above insights to develop an extended model for commercialization of AMTs involving transfer of technology from an RTO to SMEs in India.

Discussion

In the previous sections, existing literature and findings from our case studies were analyzed. Insights coupled with suitably identified sub-processes from existing TVC models are used to propose a new TVC model (Fig 8). Analytical conclusions are described under each sub-process and sources of each dimension are indicated in parentheses. The model proposed in Fig 8 attempts to address the first research question.

Analysis of the DSC technology provides an opportunity to investigate the relationship between the existing literature (i.e. CTM) and a real-life case. This section proceeds with further elaboration of the insights generated.

Competition

Single sourcing concerns have long been associated with the DSC technology due to its availability only from a company from North America at extremely elevated cost.

Other providers of DSC equipment from countries like China, Spain, Russia, Ukraine and Finland did not have any significant market base and the confidence in their DSC equipment was at best modest due to relatively higher efforts by ARCI to prove the performance of the detonation sprayed products in carefully identified segments of the Indian market. So, there was no significant competition on this front either till ARCI initiated DSC's commercialization efforts in Indian market.

Technology Introduction, Applications and Market Development

The main approaches adopted for applications and market developments are: First, ARCI targeted its communication to top management and technical professionals to educate and convince the aerospace segment. This approach was adopted in view of a potential end-user company from the aerospace segment already familiar with the benefits of similar coatings from other sources. Familiarity with similar products, acceptability of innovative solutions, and the ability of DSC to achieve desired goals were major criteria for choosing target segments. Due to their stringent performance criteria, success in engaging the targeted aerospace sector played a key role in generating confidence among other less demanding segments.

Second, niche applications and market development strategies were adopted for developing the DSC market. Niche areas were identified by comparing relevant coating properties associated with DSC *vis-à-vis* other thermal spray processes like High Velocity Oxygen Fuel (HVOF) spraying and Air Plasma Spraying (APS). Third, DSC coatings-based applications were developed to capture two or more segments of the coatings market (a multiple-niche strategy) rather than a single segment (a single-niche strategy).[60] This strategy has the distinct advantage of diversifying risk. Fourth, we can analyze the roadmap adopted for commercialization of DSC based products according to Ansoff's Product – Market Grid [60] (Table 12).

A combination of strategies as shown in Table 12, was used to capture the market. Application and market development efforts were initiated by ARCI and then accelerated by four technology recipient companies. A strategy involving market penetration and development for already available coatings coupled with product development and diversification for newer coatings was used. For example, the chromium carbide-nichrome (Cr_3C_2-NiCr) coatings previously demonstrated to enhance wear resistance of aeronautics components were applied to wear-prone components for which similar properties and performance criteria were desired. Similarly,

Table 12 — DSC Commercialization strategy in terms of Ansoff's Product – Market Grid

	Current products	New products
Current markets	Market penetration strategy	Product development strategy
New markets	Market development	Diversification strategy

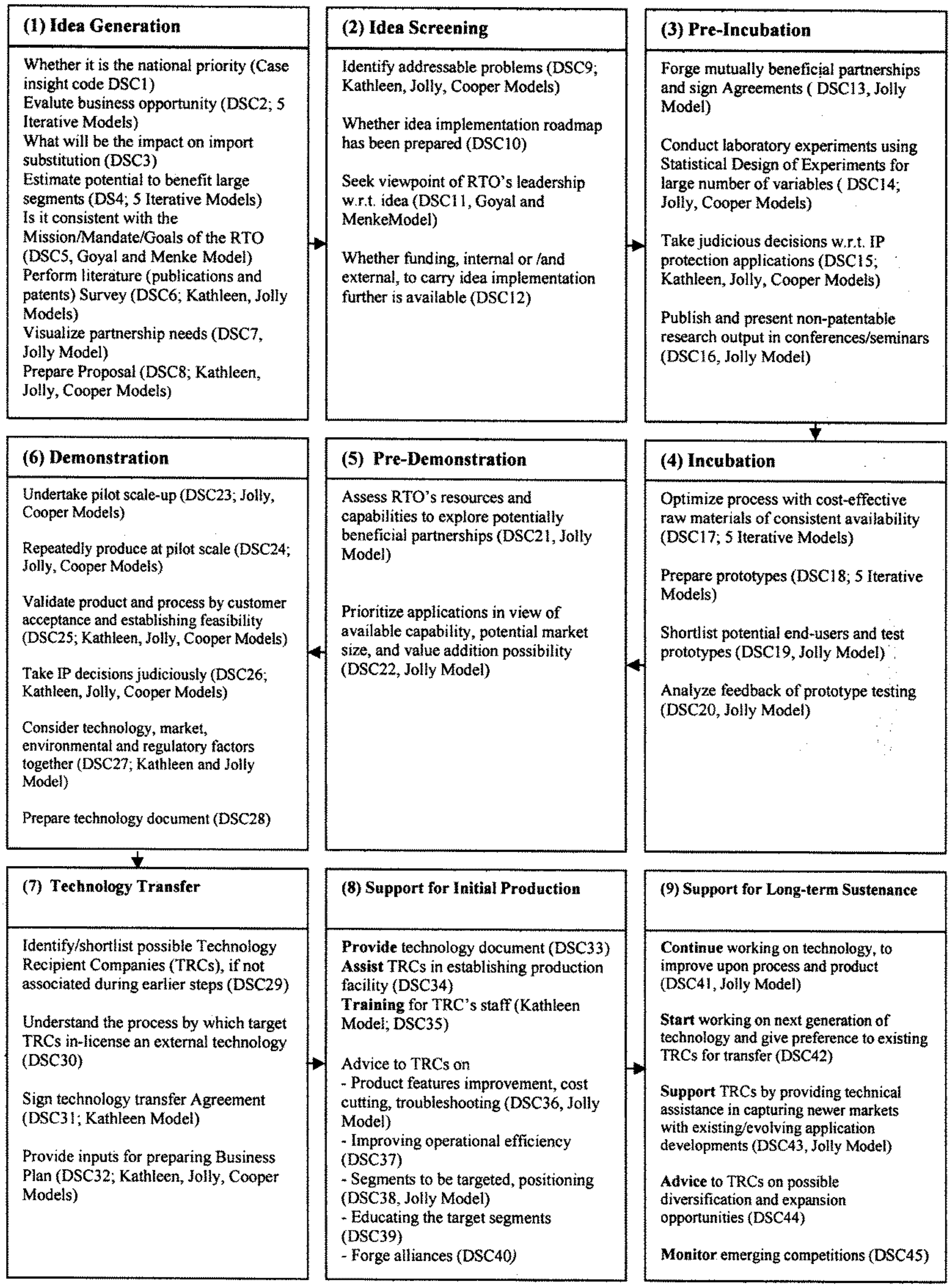

Fig. 8— Proposed TVC model

When oxide coatings were being targeted at sectors like pump and cable manufacturing, newer markets for these coatings were simultaneously explored in other sectors.

Technology Transfer and Commercialization

Technology purchases are complex, involve a high level of decision making, and are expensive,

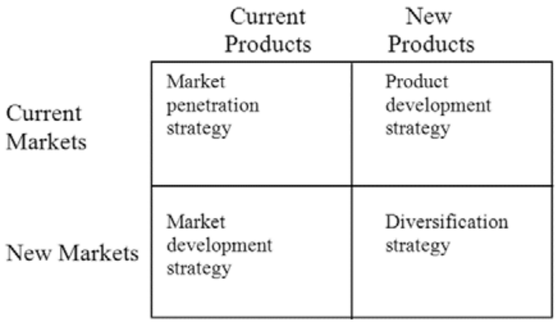

Fig 9 — Time frame for material based technologies

infrequent and risky for a company. The approach adopted to convince entrepreneurs to take-up DSC technology commercialization therefore involved emphasizing necessary attributes such as market acceptability, chances of quick pay-back, technology validation (as shown by the extended phase of job works carried out prior to technology transfer of DSC technology).

Commercialization Duration and Market Entry Timing

Twenty years from invention to widespread use has been the usual time-frame for materials-based technologies[6].In the case of ARCI's DSC technology, the time span from ascertaining techno-market insight to widespread use of the technology took almost 15 years, which is near the norm for the materials sector (Fig. 9).

Conclusions, Implications, and Limitations

Major Insights

This study has provided the following useful insights through in-depth investigation of a longitudinal case, thereby addressing the second research question. First, potential techno-commercial attractiveness was used to initiate the program. Second, identification of appropriate target segments, access to low-cost governmental funds, regionally exclusive technology transfer, and forging of useful alliances during the TVC contributed to commercialization success.

Third, we find that various tools in the marketing mix were utilized to expand the applications. Metal, alloy and metal-oxide coatings, in addition to the pre-existing carbide coatings (products), were developed to provide better replacement of similar imported coatings used by existing users. Efforts were made to provide solutions preferred by distinct niches and highlight only those attributes of a specific coating that were relevant to a targeted segment (flexible positioning). Before approaching entrepreneurs for effecting commercialization, ARCI had also generated substantial revenue through job work indicating the satisfaction of end users with the performance of coatings and their affordable price (right product and acceptable pricing). This is consistent with Mohr *et.al* (2011)[61] contention pertaining to the need of an intimate understanding of end-user requirements for a technology-based products. These coatings were made available at locations convenient to end-users (know-how transfer to four start-ups located at four different places in India was a step in that direction so that end users located in nearby places could get their components coated by detonation spray facilities). Communication and promotion programs were targeted both at end-users and at entrepreneurs interested in commercializing DSC technology.

Implications for Practitioners

This study reveals strategies useful for practicing managers. RTOs, specifically in the AMT sectors of developing economies like that of India, can employ these strategies to enhance chances of technology commercialization success.

Implications for Researchers

Further research is necessary in order to produce commercialization models for the advanced materials sector in an Indian context. These can be proposed and iteratively assessed to develop a deeper understanding of local phenomena.[62] This can be achieved by using insights from multiple case studies to produce a viable model, and then validating this model using evidence from other studies. By adopting this approach we can produce a generalized framework for advanced materials technologies commercialization.

Limitations

Inferences from one case study may be idiosyncratic, and generalizations from such a study may not be appropriate.[63] We agree with this principal, yet combining results of our study of DSC commercialization involving public-funded RTO and SMEs with others from different organizations, and developing national standards for India, may strengthen the model. However, unique and revelatory studies often involve only a single case[43] and this paper provides a first step in understanding the process. These apparent limitations of single case studies can therefore be seen as an opportunity for future researchers.

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