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The design of publicly funded R&D consortia: preliminary learnings from a longitudinal field-case study

PABLO E. Pinto
UNIVERSIDAD CATOLICA DEL NORTE
Escuela de Ciencias Empresariales (Business School)
ppinto@ucn.cl

Peter Knights
The University of Queensland
School of Mechanical and Mining Engineering
p.knights@uq.edu.au

Damian Hine
The University of Queensland
Business School
d.hine@business.uq.edu.au

Abstract

Publicly funded R&D consortia are an important worldwide governmental policy instrument, but there is a disconnection between desirable public policy and the actual mechanics of their design and maintenance. In countries such as Australia, these long-term concerns for effective design of publicly funded R&D consortia have prompted numerous policy interventions, which have been designed to bring industries, universities, and governmental agencies closer together in a triple helix model. However, the performance of R&D consortia that have resulted from policy interventions in Australia has been equivocal to date and more research is needed. This paper addresses this gap by presenting a longitudinal single-case study of the longest running and Australia's first government and industry funded mining R&D consortium, CRCMining. This study reviews how CRCMining has evolved from an initial research-driven organisation into an industry-driven one by adapting its governance, funding, and IP structures over time. In this process, CRCMining's technology transfer model has also evolved from an earlier focus on commercialising its technologies via establishing a number of operating spinoff companies, to a direct licencing approach. This model was found to be more appropriate to the industry and to the requirements of its members, particularly original equipment manufacturers (OEMs), as it also reduced cash expenditures and internal tensions and created less management distractions.

However, high cash-outlays, lengthy development times, and limited funding for producing fully-commercial products and for introducing technologies in existing mining operations have hindered the ability of CRCMining to accelerate the pace of innovation. Practical implications are discussed.

1. Introduction

Innovation is a key driver of economic growth and competitiveness (Schumpeter 1939). Rapid technological development means that innovation also increasingly depends upon strategic research collaboration to be successful (Dodgson 1992). This collaboration has led to the emergence of a variety of organisational forms that span the broad business/industrial spectrum, from broad networks, to strategic alliances, joint ventures, and to an organisational form focused on collaboration for product innovation—an R&D consortium. Such strategic partnerships among private companies, governments, and academia have led the governments of many nations to realise the importance of research and development (R&D) consortia in enhancing their international, industrial, and business competitiveness (Ahn 1995; Eisner et al. 2009). This realisation has spawned numerous publicly funded R&D consortia as an institutional mechanism for promoting technological innovation, high-value jobs and, ultimately, economic growth and social development (Cassier and Foray 2002; Harman 2010).

As a policy instrument, publicly funded R&D consortia became increasingly important in the late 1970s and 1980s in Japan, the United States, and Europe (Sakakibara 1997). Authors such as Boardman, Gray, and Rivers (2013), and Bozeman and Boardman (2014) have noted that R&D consortia are still a major focus today for most governments around the world. There is, however, often a disconnect between what is desirable in public policy and the actual mechanics of structuring R&D consortia as they try to reach their goals (Moody and Dodgson 2006). In reality, many R&D consortia fail before they can deliver real benefits (Lhuillery and Pfister 2009). Thus, the challenge for policymakers and consortium managers is to find a formula for successful publicly funded R&D consortia (Allarakhia and Walsh 2012).

In countries such as Australia, these long-term concerns for effective design, implementation, and utilisation of publicly funded R&D consortia have also prompted numerous policy interventions, which have been designed to bring industries, universities, and governmental agencies closer together in a traditional triple helix model (Leydesdorff and Etzkowitz 1996). A traditional view of the triple helix theory suggests that the potential for innovation lies in the direct collaboration between industries, universities, and governments to generate new organisational forms such as publicly funded R&D consortia for the production, transfer, and application of knowledge and technology via taking advantage of economies of scale and scope. However, the performance of such new organisational forms, including R&D consortia, that have resulted from policy interventions in Australia have been equivocal to date (Yencken and Gillin 2006; Dodgson et al. 2011; Moody and Dodgson 2006), and this is indicative of the need for more empirical evidence which is specific to publicly funded R&D consortia.

This paper addresses this gap by presenting a longitudinal field case-study of the longest running and Australia's first government and industry funded mining R&D consortium, the Centre for Mining Technology and Equipment, CMTE (currently trading as CRCMining). Initially established under the Cooperative Research Centre (CRC) Program by the Australian Federal Government in 1991 to bring step-change advancements in mining processing techniques and supporting equipment, CMTE/CRCMining has become one of the most visible of the CRC Program with direct economic impacts to the mining sector reaching an estimated value of \$AU177 million in total in new technology developments and education outcomes, and approximately \$AU8 million per year in costs savings for mining companies through productivity increases as a result of work undertaken by CMTE/CRCMining (Laver et al. 2012; The Allen Consulting Group 2012). This study reviews how CMTE/CRCMining has changed from an initial research-driven organisation into an industry-driven one by adapting its governance, organisational, and funding structures over time. In particular, three questions are addressed in this paper: (a) What are the main structural features of CMTE/CRCMining?, (b) How and why have these features changed over

time?, and, more broadly, (c) if the case of CMTE/CRCMining can be considered as a typical example of a mining R&D consortium, what are the main differences in terms of the patterns of cooperation between the mining industry and other economic sectors?

The rest of the paper is organised as follows: it first describes the study's setting and discusses the research method. It then summarises the developments in the nature of CRCMining's organisational and governance structures, in its intellectual property (IP), and in its technology transfer model to elucidate the changes of this successful R&D consortium. Next, it reflects on such features in the context of the mining industry and, more broadly, in the setting of publicly funded R&D consortia. Finally, the conclusion section summarises and consolidates major findings.

2. R&D consortia as a policy instrument

Publicly funded R&D consortia are a desirable policy instrument for promoting technological collaboration among companies, as well as, between governments and academia while strengthening the competitive position of industries in relevant technologies (Hart 1993; Nagaoka and Flamm 2009). They have also been used as a means for reversing conditions of technological decline (Corey 1997; Devlin and Bleackley 1988) and for enhancing industrial relationships without forcing actual mergers and acquisitions (Webre et al. 1990; Miotti and Sachwald 2003).

Publicly funded R&D consortia are not a new phenomenon in the world for encouraging innovation (Caloghirou et al. 2003; Dodgson 1992). The modern notion of R&D consortia traces their origins to Europe and, more specifically, to the United Kingdom in the late 1910s when the newly established British Department of Scientific and Industrial Research began funding research associations "to meet the acute technological needs of British industry, the shortcomings of which had been revealed at the outbreak of the First World War" (Sigurdson 1998). However, R&D consortia only became prominent as a policy instrument half a century later in Japan's post-World War II economic recovery half a century later, and also in the United States and Europe during the early 1980s (Sakakibara 1997).

Their inception in Australia is, however, more recent. Publicly funded R&D consortia were first developed in 1991, when the CRC Program was established in the fourth Hawke Government to "deliver significant economic, environmental and social benefits to Australia by supporting end-user driven research partnerships between publicly funded researchers and end-users to address clearly articulated, major challenges that require medium to long term collaborative efforts" (www.crc.gov.au). Initially, fifteen CRCs, including CMTE/CRCMining, were established.

Each CRC is, by definition, a joint venture between several universities, a number of end-users, and sometimes, other research organisations. In the early days of the program these joint ventures were typically unincorporated (Knights and Hood 2007). Today, to facilitate decision-making and to provide better governance, all new CRCs are incorporated

There are currently 36 CRCs in Australia. The Australian Government has invested \$AU3.6 billion over the program's life with a further estimated investment of \$AU11.4 billion from universities, other research organisations and industry end-users. A recent Allen Consulting Group (2012) report has estimated the direct economic impact of the CRC Program on the Australian economy at \$AU14.5 billion since 1991. Other reports, however, have been critical to the CRCs' ability to engage directly in technology transfers (Harman 2010; O'Kane 2008), and the Australian National Commission of Audit has recently recommended abolishing the CRC Program (National Commission of Audit 2014). The latter criticism suggests the need for more studies to understand the operation and structure of publicly funded R&D consortia in the context of the CRC Program. In order to achieve this, an analysis of CMTE/CRCMining is presented. The significant changes in the

organisation that this R&D consortium underwent during its lifetime are documented, and they provide a sound basis for analysis. Although clearly limited, the analysis of this single mining case also allows for comparison with other industries.

3. Method and Data Collection

The empirical research for this study was based on the empirical, field-based case study of CMTE/CRCMining, a large and successful Australian mining R&D consortium. This case study was selected because of both its national and international relevance and its ability to present a longitudinal view of the structural changes of an R&D consortium in a specific, less explored industry, mining. A case-study approach is considered a well-suited research strategy for both improving contextual understanding (Peltokorpi and Tsuyuki 2007) and for building relevant theory (Tripsas 2009). The case study's function is not to generalise about the results (Johnson 2008), but rather to inform the operation and changes of one particular R&D consortium in the Australian mining industry over time.

CMTE originated in 1991 as an unincorporated joint venture between the University of Queensland (UQ), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Australian Mineral Industries Research Association (AMIRA). CMTE was subsequently refunded in 1997, in 2003 (when it became CRCMining) and again in 2010, thus becoming the first CRC to receive four successive program grants in the history of the CRC Program. CRCMining currently operates as a fully incorporated joint-venture between eight large mining companies, four original equipment manufacturers (OEMs), an IT service provider, and four Australian universities. It also maintains active research links with the University of Arizona in the United States, which enjoys associate member status. CRCMining has a strong affiliation with the Australian Coal Association Research Program (ACARP), which provides funding for Australian coal industry research projects. Its participating member companies include Anglo American, AngloGold Ashanti, Barrick Gold Corporation, BHP Billiton, Caterpillar, Computer Sciences Corporation Australia, Herrenknecht Tunnelling Systems, Newcrest Mining Limited, Newmont Mining, Joy Global, Peabody Energy, Sandvik, and Xstrata. It also includes the University of Queensland, the University of Newcastle, Curtin University, and the University of Western Australia.

There is another reason for studying CRCMining, quite apart from its good results and longevity. Over the years, CRCMining has undergone many structural changes, including changes in its legal organisation, its governance and organisational structures, its priorities, and its partner composition. Its top leadership has, however, remained exceptionally stable. The long-standing CEO retired only recently and was succeeded by the former Research Director. This fact allowed this study to explore the phenomenon of change at CRCMining without first having to encompass the effects of significant, internal political interferences such as that created by a change in leadership. See Gibson and Rogers (1994 Chapter 4) for some discussion of this point.

Data covering the entire life of CMTE/CRCMining was gathered from three sources: interviews, archival data, and non-participant observations.

3.1. The interviews

In total, 37 people were interviewed. Following the methodological recommendations of comparable studies (cf. Grindley et al. 1994; Mothe and Quelin 2000; Browning et al. 1995), these interviews were drawn from all levels of CMTE/CRCMining and included members from the Board of Directors (6 percent of the total interviewees), from the Research Committee (8 percent), from the management team including the former and new CEO, CRCMining executives and program leaders (27 percent) and from the staff (35 percent). To fulfill the design research objectives of covering the

entire spectrum of CRCMining and to reach a “theoretical saturation” point (Eisenhardt 1989), data was also collected from interviews with the founders, the present personnel of spin-off companies, former CRCMining employees, and the employees of member companies who were linked to spin-offs (24 percent). See Table 1 below for a list of interviewees.

 Insert **Table 1** (a list of interviewees) about here

The interviews, which ranged in length from 30 to 120 minutes, were confidential and conducted face-to-face. Some individuals were interviewed twice. In most cases, however, follow-up interviews were conducted via informal conversations/hall talk and via e-mail. With the exception of three interviews, interviews were audio-recorded and then transcribed verbatim by a professional transcription service. Transcripts enabled the researcher to retrieve after the interview specific data from the primary source, the importance of which were not fully appreciated or understood at the time of the data collection. Interviewees could also request that the audio recording be temporarily paused to discuss sensitive points in detail, but this rarely occurred. The interviews were semi-structured and focused on the organisational and management structure of CMTE/CRCMining and the organisational factors that influence the development of innovations over time.

3.2. The archival data sources

Extensive access to company records was granted to the researchers during this study. These included access to internal strategic plans, minutes of the Research Committee (RC) and Technical Committees (TC) meetings, and presentations to company members. Management meeting documents, financial statements and plans, as well as, external reports such as review panel reports, which had assessed the performance of CMTE/CRCMining over time, were also made available.

3.3. Direct, non-participant observations

Finally, the principal researcher also engaged in direct, non-participant observations on-site of CRCMining’s daily activities and key events at the headquarters of CRCMining between November 2011 and September 2013. Research carried out via direct observation of the situation of interest is also considered to be a valid method for organisational studies and is particularly useful for gaining an understanding of organisational change that is taking place in a single organisation over time (Vinten 1994; Tripsas 2009). The principal researcher was granted an office in one of CRCMining’s newest spin-off companies and was permitted to observe RC and TC meetings. This researcher also participated in several strategic planning workshops and in CRCMining’s last four annual conferences.

4. The case study: CMTE/CRCMining

The current structure of CRCMining is relatively new despite the consortium having been in business for 24 years. Some of these major changes have occurred only recently (as at 2015). These are described next.

4.1. CRCMining’s governance and organisational structure

There have been three recent major changes in the governing structure of CRCMining. First, the Board of Directors was significantly reduced in size in 2009. Second, the Technical Advisory Panel (TAP) was dissolved in 2009 and was replaced by the Research Committee (RC) and the Technical Committees (TCs). Third, in relation to the previous two changes, a

multilevel approval structure was implemented in early 2010 to support the multi-communication channels between the consortium and the participant organisations.

4.1.1.1. *CMTE/CRCMining's governance*

The Board of Directors has been in existence from the very beginning of CMTE. During the organisation's unincorporated phase (1991-1997), the Board had two senior representatives from each of the three participating research organisations. When it was re-funded in 1997 and, as the consortium moved away from a predominately research-driven focus towards an industry-driven focus, its composition was adjusted to include both an independent chairperson and industry representatives. The new Board included representatives of each of the core participants, twelve in total, of which seven were from industry. CRCMining's board membership numbers increased to 16 by 2003 and 20 by 2008, before it dropped to nineteen in 2009. The board became unwieldy as more members were added. Decision-making became slow and tedious since most board decisions were made by consensus. CRCMining's ability to monitor the management and initiate strategic changes also declined. An internal report showed that attendance rates at board meetings dropped considerably during that time to an average of one to two meetings per representative per annum.

According to internal sources, everyone accepted that the Board had become too big to function efficiently and that there were some deficiencies in governance. It took members some time, however, to accept changes to the board. The representative board, where every industry member could appoint a director, was valued by the members. It was seen as a mechanism for protecting their own power and self-interest. It took two years to effect the change to a streamlined representative structure in early 2010.

This streamlined representative structure, however, led to the development of communications problems between the board and non-board members. The collective expertise of the larger Board was also lost in the process. To ameliorate the cross-communication problems between the Research Committee and the Board, the Research Committee's chairperson began attending board meetings to report on the progress of projects and on how and whether industry members were supporting the management initiatives of CRCMining.

CRCMining operates today with a traditional company structure where the Chief Executive Officer (CEO) reports to the Board of Directors. This latter now consists of a minimum of four and a maximum of eight directors (there are currently seven) with the majority being independent of the members. The current Board is chaired by an independent chairperson and this includes the CEO, two representatives elected by the mining companies, one representative from the research participants and two representatives of the remaining industry participants. Consistent with CRCMining's central concern for technology transfer, the current chairperson is a prominent company director and is a founder and CEO of a leading Australian venture capital firm.

The Board of CRCMining operates now with three sub-committees: the Research Committee (RC), the Audit Committee, and the Appointment and Remuneration Committee. Through its quarterly meetings, the Board of Directors is responsible for setting the overall policies and research priorities and for overseeing technology transfer and commercialisation activities. The Audit Committee assists the Board in carrying out its duties in regard to its financial reporting and its legal compliance obligations. This committee consists of three non-executive directors and meets twice a year. The Remuneration Committee also consists of three non-executive directors and is responsible for reviewing the remuneration of all senior staff. It meets as required.

4.1.2. *CMTE/CRCMining's Research and Technical Committees*

The second change experienced by CMTE/CRCMining involved a gradual but equally important process. The Technical Advisory Panel (TAP) had been established by the Board in the 1992/93 period to provide the CEO with guidance on the research and educational programs, advise on improving the company's relationship with industry, and on the development of a formal channel for technology transfer. This panel, which met three to four times a year, was made up of seven senior mining industry executives and one academic. None of them were formal members of CMTE at the time.

In August 1993, the Board of Directors, then comprising two representatives from each of the three research participants (AMIRA, CSIRO and UQ), established a Research Advisory Committee (RAC). This was established to coordinate the interface between the Board, the seven main research groups (four divisions in CSIRO and three university departments), and the CEO. While TAP reported back to the CEO of CMTE, this new committee reported directly to the Board. The committee's functions included advising the Board on research and finance-related matters, on approving the R&D resources provided to the consortium, on ensuring that the scope of the project work was aligned with the strategies of both CMTE and its research partners, and that the level of resources, which the consortium planned to use to conduct R&D activities, were acceptable to the research partners. This committee was composed of the chief officers of the CSIRO divisions and the heads of the university departments with which CMTE then interacted. They met four times a year.

CMTE was predominantly research-driven during this phase and its research work was conducted as discrete projects. Projects were managed by a project leader who reported to a program manager. The program managers were all senior academics or researchers from the participating research organisations. The communications and cooperation between the various research programs were poor because CMTE had a silo-based, vertical organisational structure.

Both the TAP and the Research Advisory Committee grew in numbers with the subsequent changes to CMTE's membership and, by 1997, the ten members of the TAP were all linked to CMTE's industry-participant organisations, although its role still consisted of advising the CEO. The new Research Liaison Committee (RLC), which was formerly known as the Research Advisory Committee (RAC), then consisted of eleven members. Despite the major restructuring of the Board to include a predominance of industry members, the RLC maintained its traditional membership-base of academics and senior researchers. The RLC was disbanded in 1999 for it was seen as an unnecessary duplication of the TAP. The TAP included one representative from each of CMTE's industry and research participants, and the consortium's management team (the CEO, the four research program leaders, the educational program leader and the business development manager).

As more and more industry members were added to the consortium, TAP's membership quickly reached unmanageable proportions (from fourteen members in 2003 to a high of thirty-one in 2008). As the TAP was convened to discuss all research matters in all research programs (four by then), the larger TAP, like the Board, became dysfunctional and participation in it began to wane.

By mid-2009, it also became increasingly evident that this old structure was hindering the ability of CMTE to engage with companies beyond particular interests of the members of the TAP. CRCMining then sought structural changes in an effort to improve membership participation. It searched specifically for new governance structures that would be capable of bringing greater control, efficiency, and coordinated planning to the expansion of the organisation's research programs and to its R&D activities. It reviewed the ACARP's model. This used a three-layer approval structure that consisted of a board, a research committee, and five technical committees. The five technical committees were responsible for overseeing project development and for their ranking in the priority areas in which ACARP was seeking research proposals. By the end of

2009, CRCMining had adopted the ACARP-based model wherein the Research Committee assumed the old role of the TAP, and the Technical Committees, which were established for each of the four program areas, provided a forum for industry members to discuss technical problems and work with the research managers to explore potential solutions to their problems. Multiple TCs enable engagement along specific interest lines and multiple representations of skills in the same company. This also led to a greater communication exchange between member companies and CRCMining researchers. The outcomes of the technical meetings were reported at the RC meetings.

This model was not completely new to CRCMining. On the contrary, it resembled the old RLC/TAP dual model in its structure. These consortium-enforced new procedures avoided many of the past problems such as the unnecessary duplication of functions. The TAC membership, for example, was limited to one voting representative from each of the industry partners who were aligned to those program areas. More representatives could attend each meeting, but the TC only included them as non-voting members. Similar limitations applied to the CEO and to the Research Director, who could attend each of the TC meetings but only as a non-voting member. This prevented researcher-bias and thus allowed a more objective appraisal of projects.

Another feature of the new model was that the Board received feedback on the progress of the research projects but did not get directly involved in the annual selection, or in the technical review of on-going projects. This became the function of the RC. In this function, the TCs were to assist the RC, with all four TCs effectively reporting to it. The RC was to comprise the chairperson of each TC. The RC and TCs were to be chaired by an industry representative who then reported directly to the Board. The CEO could also bring other concerns and interests from the RC and from the participating companies to the Board in this structure. However, in stark contrast to the old RLC/TAP structure, which appeared at times to deliver less-meaningful membership participation in the project decisions, the new approval structure promoted an engagement between the individual participants of the RC and TCs (integration), and between CRCMining's employees and the industry participants in specific areas of mutual interest (synergy). Figure 1 depicts a diagram of this new approval structure.

 Insert **Figure 1** (The governance and approvals structure of CRCMining) about here

4.1.3. *CMTE/CRCMining's* multilevel organisational structure

The third change is related to the first two. In stark contrast with its older research-driven structure, CRCMining's current organisational structure is dominated by industry members. These industry representatives of the RC and TCs are usually different types of persons from the board members. The board members, for example, mainly come from the top or from very senior positions in their own companies. The TC members are often technical people who work predominantly on mine sites in middle management or in supervisory positions. The RC members are likely to report to the board members in their own companies. They include persons from senior-level leadership, from middle management, or from supervisory positions in their organisations. This multi-layered structure promotes the development of multi-communication channels between CRCMining and the industry members or the research participant organisations. These communication channels operate at three distinct levels: the top management (strategic), the middle management (intermediate), and the mine site (operational) levels.

The strategic level involves decision-making that is related to the five-year road map, to the annual portfolio of R&D projects, and to the research budget of CRCMining. This then ensures that CRCMining's research programs are, at the highest level, aligned to the strategic objectives (and funding) of the participant industry members. CRCMining's funding

comes from direct Government contributions, members' fees, and direct project funding from industry members. The Government does not participate in the management of CRCMining. Strategic-level relationships help to highlight areas of agreement but, more fundamentally, they assist in the development of trusting relationships. Board and RC members act as effective conduits for communication between the consortium and their own companies, and this aids the process of collaboration.

At the intermediate level, the formal mechanism for collaboration between the researchers and industry personnel is the TCs. The new role of the TCs is to guide each of the consortium's research programs in a particular direction. Members of the TCs are in close contact with each other to facilitate the transmission of critical information about common issues in the mining industry. The TCs also facilitate communications with middle management and the mine sites. This intermediate level reports directly to the RC at the strategic level.

The operational level consists of a number of discrete R&D projects. These are aligned to the strategic interests of the participant industry members. As projects mature, CRCMining expects one or more industry partners to directly engage in their funding, thus giving them control over the use of the research results. CRCMining sometimes engages in projects with non-member companies when such work is seen to have strategic value for their own participating industry members. A complementary aspect of the collaboration at operational level is CRCMining's educational program. CRCMining has funded 83 research higher-degrees at its four partner universities over twenty-two years. Of these graduates, 40% have been placed with industry, 44% have chosen research careers, and 16% have other destinations. This uptake of its graduate students by both research and private organisations not only reflects the success of the research program, but also, contributes to a well-placed alumni-base that can support future research work on mine sites and across potential research partners.

The organising principle around CRCMining's three-layered structure has another relevant role: it provides support for its technology transfer and commercialisation activities. CRCMining's preferred commercialisation strategy is to engage with OEMs and service-provider members and, particularly, with its mining company partners, to accelerate the transformation of research developments into products and services. By sitting at the same table, the OEMs, the service providers, and the mining companies are directly involved, from the very early stages, in commercial discussions and negotiations. This relationship fosters the probability of effecting this transfer of technology. A graphical representation of this multilevelled structure can be seen in Figure 2.

 Insert **Figure 2** (The multilevel organisational structure of CRCMining) about here

4.2. CMTE/CRCMining's legal, intellectual property (IP), and technology transfer models

CRCMining is legally managed by an unlisted, tax-exempt, public company that is limited by guarantee (a not-for-profit research company), CMTE Development Ltd. Instead of shareholders, CRCMining has members who provide seeded funding to research projects and internal activities. CRCMining, through CMTE Development Ltd., retains ownership of the IPs the consortium and its research partners develop. The advantages of this company structure are a limitation of legal liability, and a creation of an entity that owns all of the IP generated by R&D activities carried out by the university partners. To achieve this, the university partners agreed to waive their rights to IP, giving CRCMining the right to negotiate and commercialise technologies. The reason that the university members agreed to this arrangement is the re-investment of

the commercial earnings in new R&D. Revenues earned by the company's commercialising of the IP are, in general, not drawn as dividends.

This legal arrangement provides an umbrella agreement for managing the IP of all R&D activities conducted by CRCMining's university partners. Additionally, member companies do not have to dedicate valuable time and resources to negotiate IP arrangements when initiating new research contracts with the individual universities. It also has the advantage of concentrating IP ownership in the hands of people who understand the mining industry and are better placed to estimate the value of potential innovations (Knights and Hood 2007). Unrealistic expectations value by university administrators unfamiliar of industry needs can create divisions between company and university members, and also disenchant industry members with the R&D consortium, as the literature reports (e.g., Feller 2009).

4.2.1. *CMTE/CRCMining's funding/IP management model*

CRCMining has historically worked on discrete projects. Although this function has remained essentially untouched for almost two decades, CRCMining's funding structure began a modernisation process in the late 1990s in order for the company to move toward a more commercialised focus. Since then, CRCMining's research work has operated in two main spheres: fundamental and project-based R&D.

The funding model is relatively simple. The fundamental R&D is funded entirely from the consortium's own financial resources, which are called discretionary funds. These are made up of the Government's funding grant and industry partner fees. Discretionary funds are also used to pay the running costs such as property rental, legal costs for protecting IP, and some head-office salaries. Fundamental R&D develops technologies to the point of demonstrated feasibility. This enables member companies to share in the early R&D development costs to reduce financial risks and leverage the funds provided by the Australian Government. Such resource leveraging also enables the consortium to work on high risk but potentially high benefit technologies that depart from conventional practice. Historically, CRCMining has re-invested at least 25 percent of its core funds in long-term, fundamental R&D. Because discretionary funds are used in the "proof of concept" stage, all members receive regular feedback on the technology and IP developments via the quarterly meetings of the Board, and from the RC and the TCs.

Progress beyond the scoping point (building prototype systems and the commercialisation stage) requires research work to enter the project R&D phase. This phase is usually directly supported by industry. Technologies that have coal industry applications are usually submitted for funding consideration to ACARP and, for other projects, are also marketed through AMIRA. Income from a number of licencing agreements and from the associated companies, which were established to commercialise the developed technologies, have recently produced a revenue stream that is able to fund more research activities.

There are a number of steps before the commercialisation stage. It is necessary to take a project from the "proof of concept stage" to a demonstrative prototype (or demonstrator) and then a full-scale field prototype. Developing prototypes involves a combination of core and applied research. Full-scale field prototypes can sometimes be prohibitively expensive for the mining industry, especially in the area of large mining equipment. Some previous projects have thus "jumped" from the demonstrator prototype stage to the fully commercial product stage. An example of this is the Universal Dig and Dump (UDD), a novel rigging and control system for a dragline's bucket. This technology went from being tested on CRCMining's 1/10th scale dragline to field trials and to full implementation on a BMA machine in three years without first going through a full-scale field prototype stage.

In order to share development risks, CRCMining will not proceed to develop a R&D project to field prototype stage without first gaining investment from a partner company. This provides a stop/go mechanism to ensure that ongoing projects will have the necessary industry support and will be used and valued by it. Discretionary funding may still be applied during this stage to maintain a stake in the development of any IP. It is expected, however, that industry members will provide the bulk of the funding for this step. Through their interaction with the Board and with the RC, the member companies have the first right to invest in the process of taking projects to the field demonstration stage. While other member companies receive only summarised IP information, only those companies who are funding the field prototype receive a full disclosure. This enables the latter to estimate the potential value of the IP (Knights and Hood 2007).

The final stage of development involves taking a project R&D from the latter point of the field-prototype to a fully commercial product. This requires considerable funding to further enhance the safety, reliability, and maintainability of the product, and to establish product support and marketing capability. For an R&D project to make it to this stage, a commercialisation agreement must first be signed, with the understanding that any further development is the financial responsibility of the owners of the technology. This final mechanism ensures that the consortium does not fund projects that do not have truly viable commercial outcomes. CRCMining also establishes spinoff companies to protect its intellectual property. Many are IP-holding or shelf companies, which also limits their exposure to liabilities. Companies that support the development of the technology during the field-prototype stage either have a significant stake in the spinoff company or have an exclusive licence for the technology for a pre-defined period, or have both. All IP details remain confidential to the direct sponsors in the commercialisation stage. The normal progression of a research project from the basic research to the prototype and the technology transfer stages is shown in Figure 3.

 Insert **Figure 3** (The pipeline model of CRCMining) about here

Figure 3 illustrates that, the more a research project progresses through its life cycle, the more the exclusivity of rights—in particular to the project sponsors. Similarly, as a project progresses through different stages, the risk window is shifted from a high risk of technology failure to a high risk of commercial failure.

4.2.2. *CMTE/CRCMining's* technology transfer model

R&D consortia are ultimately judged on the basis of their ability to transfer their technologies in the most effective manner to their industry members (Gibson and Rogers 1994). CRCMining is no different. CRCMining has historically relied on two fundamental mechanisms to effect the transfer of its technologies: using associated (spinoff) companies, and licencing. CRCMining's early strategy was mainly the former. Industry partners that supported the development of the technology often received a significant stake in the spinoff company. Most of the member companies were, however, mining companies whose core business lay in the extraction and the processing of mineral resources, but not in the selling of mining technologies. This meant that CRCMining soon encountered significant problems in managing its spinoff companies. Although they (the mining companies) were able to provide funds to help develop the technologies commercialised through the spin-off companies, these partnerships were never sustainable. Large-scale mining companies usually preferred to deal with companies of a similar size, and the small spinoff companies were not seen as being equal.

The interplay between being a consortium member and, simultaneously, a partner in a spinoff company also became problematic for CRCMining. It, for example, could not negotiate better economic terms or penalise its members when they

had not fulfilled their contractual obligations to the point that those actions could jeopardise their membership in the consortium. In some cases, the use of spinoff companies also created intra-consortium cannibalistic conditions since some of the spinoffs targeted markets where the member companies already played a role. This created unnecessary tensions between CRCMining and its partners and, particularly, with its OEMs companies. As a result, CRCMining abandoned its spinoff strategy in early 2009.

The intermediary role of the consortium's OEMs and service providers did, however, become a critical advantage in CMTE/CRCMining's conversion of the research outputs into industry outcomes. This often meant licencing the technology to a supplier, which takes advantage of the consortium's unique position for leveraging the delivery capabilities of its OEMs and service company members. Table 2 summarises the commercial agreements established by CMTE/CRCMining.

 Insert **Table 2** about here

5. Discussion

This case study suggests that mining R&D consortia are affected by design challenges similar to those impacting consortia in other industrial sectors. These challenges include concerns about establishing effective governance mechanisms that facilitate greater engagement by industry participants in the direction and management of the consortia's research activities (Allarakhia and Walsh 2012; Xia et al. 2012). They also include concerns about the strategic protection and ownership of IPs (Cassiman and Veugelers 2002), and the consortia's commercialisation choices (the latter includes choices from equity use to arm's length licencing) (Park et al. 2010). Mining R&D consortia are, however, unique in two aspects: managing competition between the mining companies is relatively easy and, due to structural and funding limitations, the lead time for developing and commercialising new technologies is difficult to alter even when using an R&D consortium.

The former aspect (managing competition between the mining companies) relates to the difference between horizontal and vertical relationships. Economic Theory suggests that vertical cooperation is less likely to produce opportunistic behaviors (Miotti and Sachwald 2003; Atallah 2002). In stark contrast to the vertical cooperation that links companies with suppliers and/or customers, horizontal cooperation directly links rival companies in the same marketplace. Companies collaborating in horizontal relationships tend to be more vulnerable to their rivals' potentially opportunistic behaviors. This includes a race for any new knowledge and a misappropriation of any such knowledge that is not readily protected (Khanna et al. 1998). R&D consortia that involve rivals are thus more difficult to design (Silverman and Baum 2002), and more likely to raise proprietary concerns where competitors are reluctant to disclose confidential information (Cassier and Foray 2002). Not surprisingly, horizontal relationships have been historically less prevalent than vertical ones, and often limited to areas where there is a common enemy (Corey 1997; Arranz and Fernández de Arroyabe 2008).

This study reveals that the pattern of cooperation is, however, different in the mining industry when compared to other industrial sectors if the case of CMTE/CRCMining can be considered as a typical example. Three structural factors contribute to this finding. First, while mark-up profits are readily available in final products in other industrial sectors, commodity prices in the mining industry are instead determined by external metal market forces such as the metal exchanges, merchants, and industry stockpiles (Rauch and Pacyna 2009). The potential for mark-up profit is therefore non-existent in final, mining products since sale prices are beyond the control of the producers (Bartos 2007). There is thus no need for mining companies to compete directly in the markets as occurs in other industrial sectors (National Research

Council 2002). The potential for leaking proprietary knowledge to rivals through collaborative relations is, therefore, usually marginal in the mining industry.

Second, as a basic rule for the industry, the mining companies never keep private anything to do with occupational health and safety (OH&S) and environmental risks. The mining industry understands that they have all endeavoured over the last 20 to 30 years to improve the way in which risks are managed. They also understand that a major accident, no matter where it is, can potentially tarnish the entire industry. This is unacceptable, particularly in an industry that often works under intense public scrutiny (Albanese and McGagh 2011). So, when new technologies or processes that can improve OH&S or risk management for the mining industry are developed by any of the mining companies, these will be immediately accessible by the entire industry without restrictions. This also extends to their social engagement. It is thus relatively easy to persuade mining companies to collaborate in R&D since they do not regard mining technology as their core business, nor their competitive driver. In addition, mining companies have no incentive to collude as they deal with commodities. As a result, the companies have all the incentives for, but do not bear the risks of, R&D cooperation. The R&D consortia model, which involves horizontal relationships between competing companies, is thus well suited to the mining industry, but is not necessarily well suited to companies in other industrial sectors.

Third, the development of technology in the mining industry is an expensive and lengthy process. Prior studies indicate that the development times for mining equipment and associated technologies are typically in the order of seven to ten years (Bartos 2007), with some step-change projects—technologies that can transform the mining industry over time—often taking in the range of 20 years to enter commercial operation (Upstill and Hall 2006). These development times match the time profile of the pharmaceutical/biotechnology industry (DiMasi and Grabowski 2007) but compares negatively to other high-tech industries such as computers, where new product introductions usually only take a few months (Datar et al. 1997). R&D consortia have played a major role in accelerating time-to-market developments and the commercialisation of emerging technologies in several industries (Schultz 2011; Flamm 2009).

The CRCMining case study indicates that accelerating technology development and deployment will be a difficult goal to achieve in the mining industry because of the high scale-up costs involved in transitioning new mining equipment from the laboratory to full-scale field prototypes. These costs are in the range of millions of dollars, with the full implementation process sometimes taking several years. This includes laboratory testing and, for safety reasons, extensive periods of on-site trials. The conversion of the first dragline to the UDD system at BMA's Peak Downs mine initially took three years but, since the project went from a one-tenth scale to full implementation, the stabilisation of the technology and solving the technical problems associated with its early implementation took several more years. The initial budget for BMA's retrofit of this UDD technology was less than \$AU10 million, but current estimates indicate that it was more than \$AU10 million per machine without considering the stoppage time or disrupted operations. Other CRCMining technologies such as the Tight Radius Driller (TRD) and the Oscillating Disc Cutter (ODC) are expensive to develop, and demand lengthy development times in excess of twelve to fifteen years to move from the prototype phase to pre-commercial testing. CRCMining, BHP Billiton, and BHP Billiton Mitsui Coal have invested many millions in TRD since beginning the research in 1996. Despite this investment, the TRD is still considered to be a technology that still requires some additional funding testing before it will become a reliable commercial product. The ODC program started in 1994 and the full-scale pre-commercial prototype was commissioned in 2006. A new prototype machine for a new mining application was recently trialled in late 2013.

Another factor explaining the difficulty to accelerate the pace of innovation is that often CRC such as CRCMining often invest in new developments far more than industry does. For a CRC, investments in early stages of the R&D spectrum of activities such as pure basic research, experimental research, and proof of concepts are attainable. However, moving upstream in the R&D process requires investment above consortium levels. Often, companies do not realise the impact of funding the various prototype stages (such as the laboratory, field, demonstration, and full-scale stages) needed to make new technology feasible for commercialisation. As a result, seed money to fund these middle stages is usually scarce. Instead, company members are more inclined to fund fully developed, commercially viable technologies. A gap exists then between a CRC's research and the industrial financial support needed to successfully bring technologies to commercial application. As the risk of technology failure diminishes upstream, and the risk of commercial failure increases upstream, bridging both sides of the equation (early/middle and middle/late) of the development process is difficult. That gap is considered a "valley of death" for many new technologies developed through a CRC.

A final factor explaining the difficulty to accelerate the pace of innovation in mining extends from the characteristics of the industry (i.e., the fact that barriers to entry are extremely high). In order to maintain an adequate level of mineral exploration expenditure and to enable subsequent mineral discoveries to be developed, the mining industry needs access to large amounts of risk capital (Phillips 1980). High capital expenditures and long lead times are also required in the development and construction of mines, smelters, and refiners. Once developed, they "remain in production until their out of pocket or average variable costs of production rise above the average total costs, including the capital costs, of new ventures" (Tilton 1992). Individual mines have lifetimes of tens of years to over a century (Hitzman 2002), which, in turn, leads to long pay-off periods for existing technologies and extra high risks in introducing new technologies in established operations (Ericsson 1991).

New technologies, particularly those of a revolutionary nature, also impose substantial additional costs such as development costs, rollout-time costs, and other hidden costs that appear in any major transformation, which are often in the range on tens of millions of dollars for radical or step-change innovations. In some cases the cost of the actual transformation itself is the minor factor; rather, it is the disruption to continued production that actually contributes most to the cost of implementing a new innovation. The net result of this is twofold: first, mining operations can remain captive to technology decisions made in the past (Bartos 2007), and, second, mining companies may have trouble embracing anything other than "commercially proven" technologies to avoid unnecessary costs (Dodgson and Vandermark 2000).

Although designed as a form to create a funding stream for future R&D, CRCMining spinoff model did not provide its intended effect. CRCMining spun off several companies, including some which won important technology awards. However, there is a general consensus that these spinoff companies, with the demand on CRCMining's financial and management resources, served as a costly distraction from the consortium's main activities. The high cash-outlays, the lengthy development times for mining, and the often limited funding for producing a fully commercial product and introducing new technologies in existing operations hindered CMTE/CRCMining's ability to accelerate the pace of innovation (as reported above in Table 2).

6. Conclusions

Despite the past studies of publicly funded R&D consortia, there is a limited understanding of how publicly funded R&D consortia, particularly those in mining, are structured and operated in the context of Australia's CRC Program. In this paper, we provide some answers to basic research questions concerning the structure and changes of a large mining R&D consortium in such context.

CRCMining has appeared to survive for over two decades by being a very adaptable organisation. Three design aspects have been critical to CRCMining's success: its governance structure, its management of its IP, and its composition and management of its members' vested interests. The interlocking governance, organisational, and approval structure of CRCMining comprises three levels:

- A strategic level to oversee the direction and funding of the consortium's research activities
- An intermediate level to bring in industry technical-expertise, and
- An operational level for facilitating the direct deployment of on-site projects. This structure represents a more sophisticated stage of development in the history of CMTE/CRCMining and is similar to a successful European alliance reported by Linnarsson and Werr (2004).

A key feature of this multilevel structure is that the mining and OEM end-users determine the research work that will be performed on the basis of their own technological needs. The regular oversight provided by the Research and Technical Committees during the development also ensures that expectations are adjusted according to the trials and tribulations experienced. In this structure, a professional Board dominated by industry members is charged with resolving corporate governance issues and determining long-term strategy. The board receives feedback on the progress of research projects, but does not get involved in the annual selection or technical review of projects. This multilevel structure can thus support a higher intensity of bi-directional interaction and knowledge flow between the member companies and the consortium, and so facilitates an efficient transfer of the latter's technologies.

The commercialisation step in an R&D consortium setting is only successful if the IP associated with the technology has been appropriately managed and protected (Allarakhia and Walsh 2012). CRCMining established back in the late 1990s a policy that allowed it to own all the IPs developed by its R&D activities. This gave this consortium greater autonomy in determining its commercialisation agreements and hastened its lead-times for marketing them. This arrangement has also avoided disputes and lengthy commercialisation delays involving sometimes unrealistic expectations over the value of IP ownership or "excessive" economic terms for licencing being sought by university members. Unrealistic expectations can create divisions between company and university members, and also disenchant industry members with the R&D consortium, as the literature reports (e.g., Feller 2009).

CRCMining has also maintained rigorous procedures for managing all IP issues and disseminating the outcomes among members. This has included the provision of regular feedback on the technology and IP developments to members via the quarterly meetings of the Board, and of the meetings of the RC and TCs during the early phases of a technology's development. It also, importantly, has allowed member firms to protect their proprietary information during the demonstration and commercial phases.

The mining industry is also well suited to a cooperative research environment despite the existing theory suggesting that direct rivals are, in general, sensitive about the confidentiality of information that they provide to researchers in an R&D consortia. CRCMining has established three basic rules for avoiding any potential conflict of interest. These are:

- When joining the consortium, members must commit to work for the welfare of the consortium as a whole. This does not require them to relinquish their own natural interest, but allows them to balance both.
- CRCMining further requires members to declare any conflicts of interest. In practice, this may mean that some participant members will have to leave the room during certain discussions. CRCMining also takes care to ensure that

the minutes do not contain information that those members are not supposed to know. This is very important when considering that OEMs fund a significant number of R&D projects.

- Finally, if there is a conflict of interest, then the research is broken up into smaller R&D projects to ensure confidentiality. This is addressed by CRCMining undertaking projects for single members in areas where such OEMs compete in the marketplace.

The fact that CRCMining includes direct mining competitors as core participants has facilitated, instead of restricted, their cooperation. Three reasons can be given for this. The first is that mining companies do not see each other as rivals or as direct competitors. In an industry where commodity prices are set by external factors, mining companies do not compete on products or on prices. Second, this industry is often the subject of severe public scrutiny, so mining companies are more open to the sharing of critical information with the entire industry. A third reason is that mining company members also help to bring in new members and, especially, OEMs to the R&D consortium. For the OEMs, the attractiveness of participating in a R&D consortium depends on the number of potentially interested customers. Compared with other CRCs, this number is high in the case of CRCMining.

On a cautionary note, case studies have their limitations. The most significant one is that the findings of a particular case study may not be applicable to whole industries (Peltokorpi and Tsuyuki 2007). Previous studies have documented the heterogeneity of R&D consortia's organisational and governance structures across industries and geographic regions (e.g., Dodgson et al. 2008; Kim 2008). This seems to suggest that many of these documented differences are driven by idiosyncratic, consortium-specific factors such as the industry setting, the legal environment, the degree of institutional autonomy, and the general level of government support (Park et al. 2010). Such conditions are difficult to replicate, and research results for one industrial sector cannot always be extrapolated to others (for a recent comparative study of R&D consortia across industries, see Nagaoka et al. 2009).

It is still possible, however, to draw some general conclusions about what has worked or has not work at CRCMining and to highlight the lessons learned from over two decades of research endeavours and trials and errors. CMTE/CRCMining has turned around from an initial research-driven organisation into an industry-driven organisation by re-aligning its governance and organisational structures to the needs of industry members. In the process, its technology transfer model has evolved from an earlier model that focused on commercialising its technologies via establishing a number of operating spinoff companies to a direct licencing approach. This model has been found to be more appropriate for the mining industry because CRCMining or its small spinoff companies could then avoid bearing lengthy and expensive development times that so characterise the mining industry. This model is also well suited to the requirements of its industry members in that it creates less division and internal conflict. It has also been shown to have significantly reduced cash expenditures and other management distractions, and has thus allowed this R&D consortium to focus on its main tasks.

The new structure has given CRCMining sufficient authority to revise its research areas and projects in response to changing developments in the industry. As such, CRCMining's current structure resembled that of other R&D consortia such as VLSI, MCC, and SEMATECH, which relied on committees and technical advisory boards made up of member company representatives to select projects, allocate resources, and also to review them over the life of the R&D consortium (Grindley et al. 1994). More broadly, CRCMining's current operating framework appears to match the fundamental search for radical ideas and for the technology transfer of such ideas into the marketplace via industry member channels. Matching both research and practice is difficult to achieve (Roelofsen et al. 2011). The CRCMining case study points to the

importance of designing publicly funded R&D consortia in a way that balances research and commercial application. This includes the need to manage the IPs, to protect the different interests of the different participant members, to develop a funding/approval structure that can suit the different phases of the R&D process, and, finally, to establish an appropriate technology transfer model that suits the requirements of the industry and of the member companies.

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Table 1 Summary of formal interviewees

Year	Interviewees by position* (November 2011 to September 2013)	Organizational level	Internal/external personnel
2012	Chairman and President of the Board	Board of Directors	Internal
2011	Director (retired)	Board of Directors	External
2011, 2013	CEO1 (1993-2012, retired)	Management	Internal
2013	CEO2 (2012-to date)	Management	Internal
2012	Chief Financial Officer	Management	Internal
2012	Company Secretary & Legal Counsel	Management	Internal
2012, 2013	Deputy Director of Research	Management	Internal
2012	Commercial Director	Management	Internal
2011, 2012	OHS Manager, former	Management	Internal
2012	Communications Manager, former	Management	Internal
2012-2013	Program Leaders (3)	Management / University members	Internal / External
2012	Research Committee members (3)	Research Committee	External
2012	Spin-off companies personnel (9), including CEOs/founders (4), and former executives (5).	Spin-Off companies	Internal/External
2011-2013	Staff members, non-management roles (12), including researchers from university members, current staff members and former employees.	Staff / university members	Internal

* This table does not include informal conversations.

Table 2 CRCMining' spinoff companies, technology transfer strategy and timeframe for technology development

Core Technology	Company name(s), and Tech Transfer Strategy (TTS)	Timeframe for technology development
Oscillating Disc Cutter (ODC): ODC is a breakthrough technology that allows hard rock to be mechanically cut quickly and safely without requiring massive support machines. Technology developed in partnership with Mining Company consortium.	Odyssey Technology Pty Ltd. TTS: Shelf spinoff company.	Rock cutting research started in 1993; ODC project research in 1994. Odyssey was incorporated in 2000. A full scale prototype was first trailed in 2000. Licencing agreement in place with OEM since 2006. Time-to-market: 13 years.
Universal Dig and Dump (UDD): The UDD replaces conventional dragline rigging with a lighter, new arrangement for hoisting and rigging dragline buckets that shortens dig cycles and enhances payloads, improving operation flexibility and productivity in open-cut coal mining industry. Technology developed in partnership with BMA. It is also commercialised through P&H MinePro Australasia. (www.crcmining.com.au/explore-crcmining/companies-and-licensing/).	Unidig Pty Ltd (Shelf company); UDDTek Pty Ltd (Operating spinoff company) TTS: Unidig is a shelf spinoff company. UDDTek is a service company.	Dragline automation program started in 1993. UDD research program since 1999. Six draglines were retrofitted with the UDD Technology (all BMA machines) between 2003 and 2006. There have not been any further UDD retrofits since 2006. Time-to-market: 4 years.
Tight-Radius Drilling (TRD). TRD is an innovative high-pressure water jet drilling system that can drill conventional holes, rotate 90 degrees and directionally drill horizontally in a coal seam to extract methane from coal seams. Technology developed in partnership with BHP Billiton/AGL. (www.crcmining.com.au/explore-crcmining/companies-and-licensing/).	Mine Gas Capture Pty Ltd. TTS: Shelf spinoff company.	High-pressure water jet program started in 1993 (TRD in 1994). Mine Gas Capture and CBMI were incorporated in 2000 and 2001. Field trials began in 2000 at BHP Coal. In 2006, the field test program was paused for 12 months to redesign TRD. Commercial trials were re-established in 2009. Commercial trials again in 2012 at BHPB Coal. Time-to-market: 7-19 years.
Borehole Radar (BHR): BHR is an electromagnetic subsurface imaging technique which provides detailed continuous ore body and structural delineation information for mining and geotechnical applications. It was developed in partnership with the University of Sydney (www.geomole.com).	GeoMole Pty Ltd TTS: Operating spinoff company. GeoMole sells BHR directly for applications in hard rock mining, civil engineering and oil and gas industries.	Geophysical bore hole imagining research program started in 1995 at CMTE. GeoMole was incorporated in 2000. The technology underwent substantial research and development between 2000 and 2006. The first contract research was with Anglo Platinum in 2003. The company have been trading commercially BHR since 2006. Time-to-market: 11 years.

Core Technology	Company name(s), and Tech Transfer Strategy (TTS)	Timeframe for technology development
<p><u>Acumine Collision Avoidance Safety System (4CAST)</u>: 4CAST are productivity tools for fleet monitoring, and also includes HaulCheck™, OreCheck™. Technology developed in partnership with the University of Sydney and the Australian Centre for Field Robotics (ACFR). (www.acumine.com/)</p>	<p>AcuMine Pty Ltd. TTS: Acumine is an operating spinoff company. Acumine was assigned the IP for three technologies, Haul Check, Ore Check and Stope Check in 2003. Technologies were licenced to Komatsu (2008).</p>	<p>Research program started in 1999. Acumine incorporated in 2003. Acumine's advanced collision avoidance technology is offered by Komatsu as an option on all Komatsu mining trucks since 2008. Time-to-market: 9 years.</p>
<p><u>Consulting services</u></p>	<p>Dig Technologies. TTS: Operating spinoff company. Not yet trading.</p>	<p>Dig Technologies was incorporated in 2005. Time-to-market: Not yet trading.</p>
<p><u>P Logger and Torque Thrust Sub</u>: drilling tools.</p>	<p>Intellidrill Pty Ltd. TTS: Shelf spinoff company. Not yet trading.</p>	<p>Intellidril was incorporated in 2005. Time-to-market: Not yet trading.</p>
<p><u>Pegasys Dragline Monitor</u>: Pegasys monitor provides access to real time and historical data including production, machine location, vision system, and structural and electrical feedbacks. Features include GPS, CCTV, Structural monitoring, and Reporting and Analytics. Technology developed in partnership with BMA. (www.mineware.com)</p>	<p>MineWare Pty Ltd. TTS: Operating spinoff company. MineWare is a direct provider of dragline and more recently rope shovel monitoring systems (Pegasys for draglines; Argus for rope shovels) for the surface mining industry. MineWare supports a client base of mining-companies that includes BHP Billiton, Mitsubishi Alliance (its original supporter), Wesfarmers, Ensham Resources and Anglo Coal.</p>	<p>MineWare's first product was an idea that originated from UDD in 2003. The first installation of Pegasys technology was to BHP Billiton in 2005. MineWare was incorporated in 2006. MineWare has operations throughout Australia, North America, South Africa and Chile. Time-to-market: 2 years.</p>
<p><u>Track Shield</u>: Track shield Collision Control System is a computer system to minimise the frequency of bucket and track collisions on electric mining shovels. Technology developed in partnership with P&H MinePro Australasia, the support and distribution arm of Joy Global (www.minepro.com).</p>	<p>EzyMine Pty Ltd. TTS: Shelf spinoff company.</p>	<p>Automation program started in 1994. EzyMine was incorporated in 2006. Products based on EzyMine IP (such as Track Shield) sold worldwide since 2008 by Joy Global. Time-to-market: Total = 4-6 years.</p>
<p><u>SmartCap</u>: SmartCap uses a light weight technology that measures operators' brain wave activity (EEG) using sensors mounted in a baseball cap to determine the operators fatigue level. Technology development was initially supported by Caterpillar and later by Anglo American Metallurgical Coal. (www.smartcap.com.au).</p>	<p>Edan Smart Technologies Ptd Ltd. TTS: EdanSafe was established for the direct commercialisation of the SmartCap technology. The company sells directly within Australia; third party dealers/agents have been selected for the mining markets of Chile, Indonesia and South Africa.</p>	<p>CRCMining's Operator Fatigue technology for mining machinery research began in 2004. Edan Smart Tech was incorporated in 2008; it became EdanSafe in 2009. Testing began in 2008 at Anglo Coal's mine in Queensland; Commercial deployment started in Australia and Chile in 2012/2013. Time-to-market: Total = 8-9 years.</p>

Source: Own elaboration based on CRCMining's internal reports.

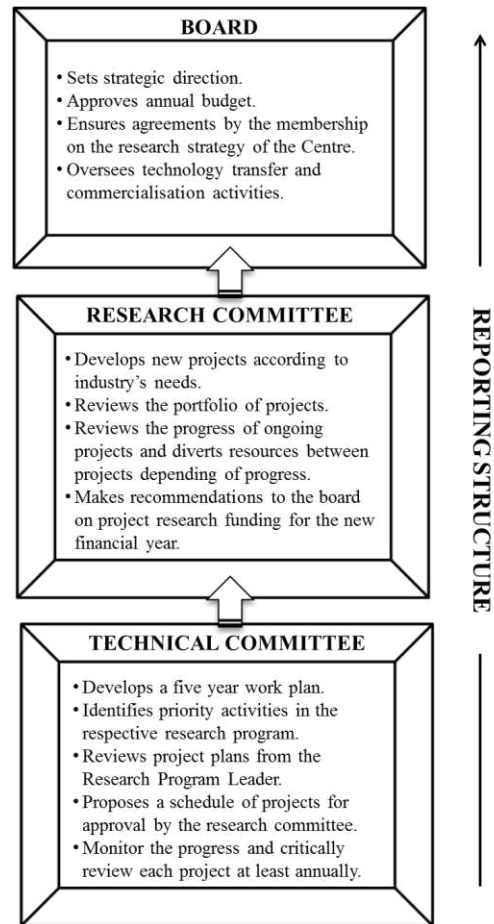


Figure 1 The governance and approvals structure of CRCMining

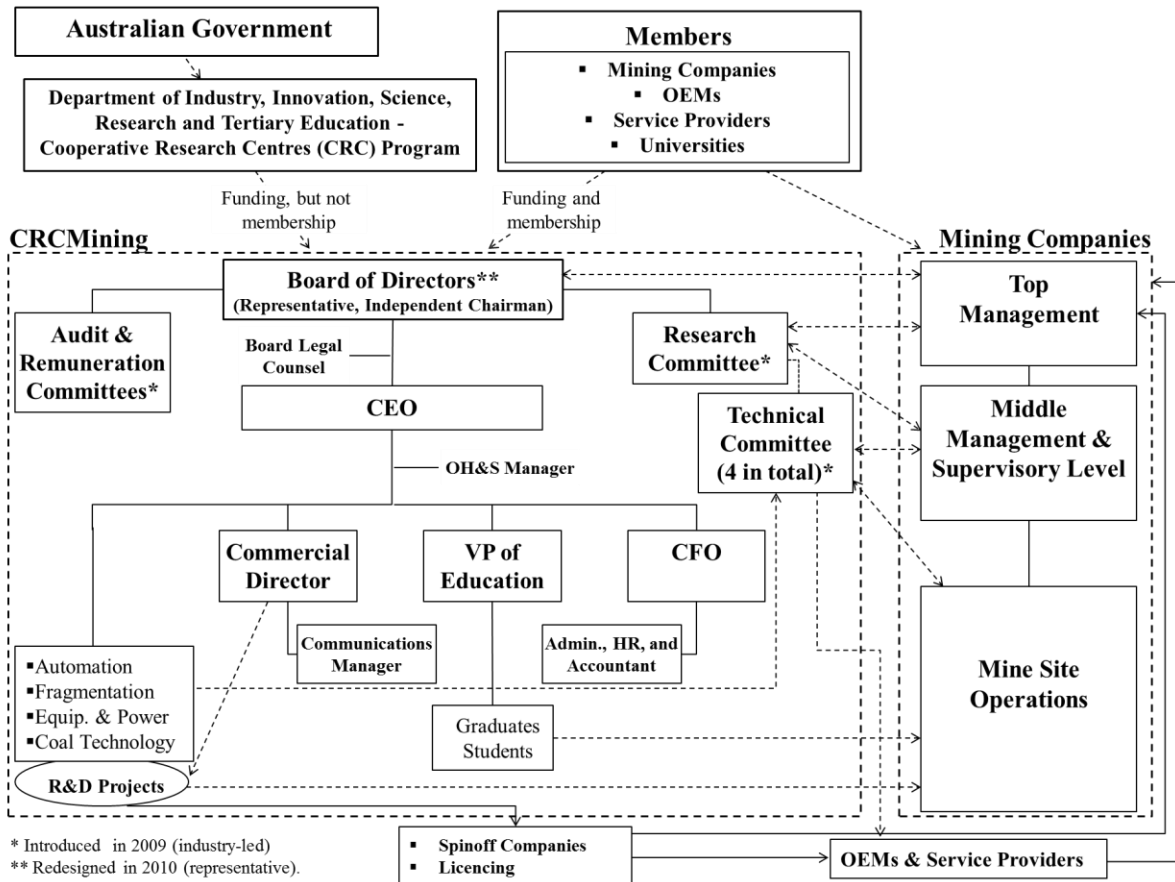


Figure 2 The multilevel organisational structure of CRCMining (as at 2013)

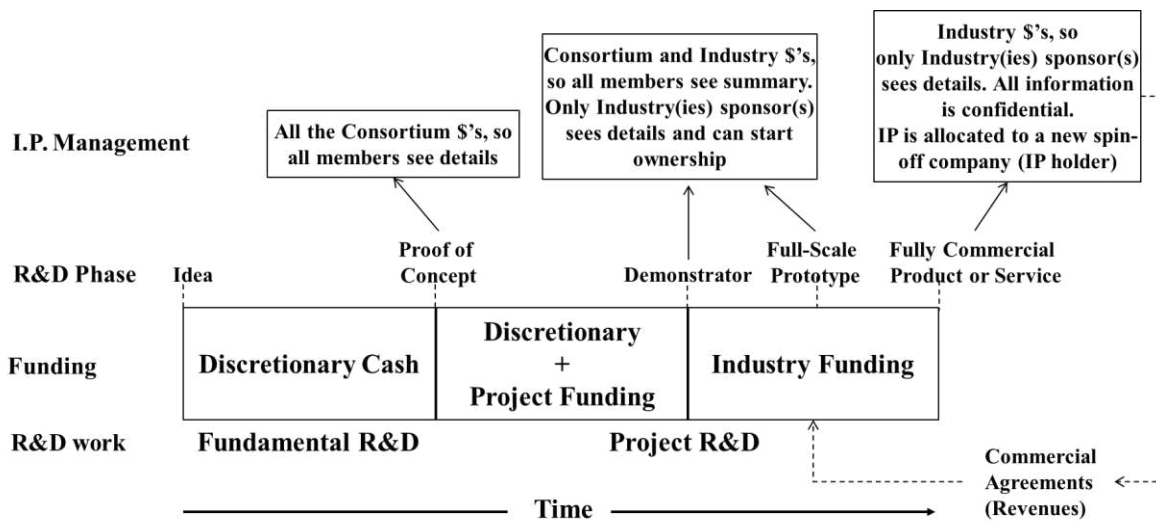


Figure 3 The pipeline model of CRCMining (Adapted from Knights and Hood 2007)