Open innovation brings forth advances for Vale and society

Projects in perspective
Lower cost and higher performance solutions

Technology and Innovation Executive Management connects and fosters new knowledge

Partnership with research support foundations creates network for scientific development
Doing research is always a challenge. Doing research for industry is an even bigger challenge, as it demands a balance between the urgent need to find practical applications to solve current problems and the time required to develop projects.

Aware of its responsibility, which arises from its position in Brazil and across the world, Vale has been playing a leading role in this field. This is not just because of the importance of research for our business, but because it is our duty to help knowledge improve people’s quality of life, in a society able to reach its full potential.

The value of information is tacitly known to all of us. When children are told "no" by one of their parents, a virtually innate strategy drives them to turn to their other parent in search of a "yes." Likewise, the value of information is very clear in many dimensions. However, information is not the same as knowledge. The latter is much more profound and it often adds a strategic dimension to information. Spreading and sharing knowledge, and not only information, is not an easy mission. Knowing what to do with information, contextualizing it and transforming it into knowledge is an essential task.

Our main objective in launching the MAIS newsletter is not just to permit the appropriation and dissemination of information, but above all to disseminate knowledge based on the results of Research and Development projects funded by Vale and conducted in partnership with institutions that operate in the fields of Science and Technology. Not by chance, this inaugural edition pays special attention to the concept of open innovation – a model of innovation that brings together corporations and the science and technology community in pursuit of solutions that, in our case, enable the company to produce more efficiently, cheaper and ever more sustainably.

On the following pages, you will understand how Vale’s Technology and Innovation Executive Management is working to meet these objectives, in interaction with various parts of the company, universities and government research funding agencies, among other players. Many projects started in this decade have already yielded consistent results or have bright prospects, in a relatively short timeframe for the development of initiatives in this area. By sharing knowledge and lessons learned, we plan to ensure that the benefits of this collaborative work can be harnessed fully.

Enjoy the newsletter!

Luiz Mello, MD, PhD
Innovation and Technology, Vale
KW: consolidated business information

Through the KnowledgeWorks (KW) platform, Vale employees have access to information on mining from more than 70 internal and external sources. They can deepen their knowledge of subjects of interest to them and look for examples to solve problems. In this large database, there are research projects led by Vale and the Vale Institute of Technology (ITV), as well as news, patents, articles and reports related to mining, logistics and ports. The platform is accessed using a separate login name and password. Click here to access the KW platform.

In addition to KW, employees can read scientific papers and technical books published by Elsevier and Springer, which are among the world’s largest publishers. To access this content, you need to be on Vale’s internal network and, in the case of materials published by Springer, log in using your corporate email address and password. See the content at http://www.sciencedirect.com and https://rd.springer.com.

Vale-CAPES Awards

The awards ceremony for the 2017 Vale-CAPES Technology and Innovation Awards will take place on December 13 in Brasilia. (CAPES is the Brazilian Ministry of Education graduate education support agency.) This year, awards will be given to the most distinguished nominees in the area of “Ecology and Nature Conservation,” including social and environmental technologies.

To select the winners, the jury will assess the innovative records, products and processes presented by each nominee, composed of scientific articles, books and book chapters, graduate course guidelines, participation in national and international academies, patents and patent applications, and prizes and honors received in the past.

Two awards will be given: one in the “Emeritus Researcher” category and the other in the “Young Researcher” category. The winner of the first category will receive a R$100,000 grant from Vale and a CAPES scholarship equivalent to that of a visiting foreign researcher (“Senior Doctor” classification) or senior foreign intern (in this case, including an extra grant of 2,100 US dollars or euros, depending on the country). The winning Young Researcher will receive R$40,000 from Vale, plus a CAPES scholarship equivalent to that of a visiting foreign researcher (“Full Doctor” classification).

Vale and Fapema hold Call for Proposals

Vale and the Maranhão Scientific and Technological Research and Development Support Foundation (Fapema) have published a Call for Proposals to select projects in the areas of “Logistics and Society.” Higher education and/or research institutions can apply for total resources of R$4.5 million (R$3 million from Vale and R$1.5 million from the state government of Maranhão, via Fapema). Private not-for-profit institutions are eligible providing that they have headquarters in Maranhão.

The projects submitted must contribute to advancement of knowledge and technology in the two thematic areas and be relevant both to the technological and industrial development of Vale, as well to expand knowledge applicable to various areas of Brazilian society.

Projects must be submitted on Fapema’s website no later than January 15, 2018. More details, such as the maximum sums allocated to projects, in line with certain categories, can also be seen on this website.
Innovating as a commitment and vocation

Vale is the world’s biggest producer of nickel, iron ore and iron pellets. Committed to contributing to the advancement of knowledge in Brazil, it is one of the biggest private-sector corporate investors in Research, Development and Innovation, in order to anticipate solutions, overcome future challenges and guarantee that its production processes are increasingly efficient and sustainable.

Throughout its history, Vale has obtained more than 6,680 patents in 111 countries, and it now has an active portfolio of more than 1,000 patents in 61 countries. In the last seven years, it has been the third most successful Brazilian company in terms of filing patents with the United States Patent and Trademark Office, and the fourth in terms of obtaining patents in Brazil.

For Vale, innovation lies in every employee, in their keen eye, in their different ways of thinking, in the healthy restlessness that leads them to continually seek to do more things and do them better, to build today the future that we want. It was in this context that in 2008 we decided to establish a technology institute along the lines of the Massachusetts Institute of Technology (MIT) and Brazil’s Aeronautics Institute of Technology (ITA). To materialize this idea, we created the Vale Institute of Technology (ITV) Department, which was later renamed the Technology and Innovation Executive Management.

Interface with academia grows

Through this new Area, Vale took a major step forward in strengthening its existing Research and Development activities and procedures. Completely aligned with the concept of open innovation, the Area promotes interaction between the company and the Science and Technology community in Brazil and abroad.

“We have formed partnerships with universities to conduct Research and Development projects, and we have also joined forces with public funding agencies to support academic infrastructure and the development of specialist human resources, and thereby advance in Science and Technology,” explains Domenica Blundi, a technical specialist in Science and Technology Cooperation and Project Monitoring.

From 2012 to 2016, Vale’s Technology and Innovation Executive Management invested R$ 714.19 million in research and technology. During this period, the Area handed out more than 600 research scholarships of eight kinds: postdoctoral study; doctorates; master; technological and industrial development; initial undergraduate scientific research; end-of-course undergraduate scientific research; university extension research; and technical support. Since 2009, the national development bank, BNDES, the National Council for Scientific and Technological Development (CNPq) and research support foundations have allocated R$72.95 million to Vale’s research projects.

Edgar Sepúlveda, a Technological Development analyst, states that a large share of Vale’s innovation projects are multidisciplinary: “The more excellent institutions and experts, both internal and external, you have in your partnerships, the better the results you will have.”

One of the executive management’s main duties is management of the Vale Institute of Technology (ITV), which currently has two sites: one in Belém, aimed at sustainable development; and the other in Ouro Preto, focused on mining technologies. Sandoval Carneiro, a technical specialist in Partnerships and Resources at Vale and ITV’s executive director, says that external cooperation began in 2010, through an agreement between Vale and research support foundations – the biggest agreement ever signed between the private sector and state Science and Technology support agencies in Brazil. Research has concentrated on four areas: ferrous metallurgy; eco-efficiency and biodiversity; mining; and energy.
The research support foundations of São Paulo (Fapesp), Minas Gerais (Fapemig) and Pará (Fapespa) took part in the first Call for Proposals. In all, 117 projects were selected and contracts were signed for 114. Total investment was around R$100 million,” says Carneiro.

In 2015, Vale held a new Call for Proposals, inspired by the first one it carried out in 2010, and this time involving partnerships with the research support foundations of Espírito Santo (Fapes) and Rio de Janeiro (Faperj). Research is focused on the macro areas of Logistics (railroads and ports), Environment and Pelletizing. According to Carneiro, 43 projects were approved: 21 in Espírito Santo and 22 in Rio de Janeiro.

“We also have an agreement in progress with Fapema, from Maranhão. In addition to logistics and the environment, we have also included the study of communities along railroads as a theme,” he says.

Challenge and established model

Luiz Mello, Vale’s executive manager for Technology and Innovation and ITV’s chief executive officer, states that the interaction made possible by his Area is now robust, but in the beginning it was necessary to break down barriers, both in academia and within Vale, due to differences in aspects such as the time taken to develop projects. As he came from the Federal University of São Paulo, where he was the provost for undergraduate education, he has been able to help bring together different points of view, acting as an ambassador for innovation.

“Making this transition was a challenging process, which motivated me a lot. Today, we have an established model not only for Vale, but one that is increasingly inspiring the industrial and academic sectors,” he says.

The Technology and Innovation Executive Management is divided into three segments: Partnerships, Research and Development; Intellectual Property and Technological Intelligence; and Planning and Financial Management. “The executive management is a milestone. It has succeeded in repositioning Vale in terms of its activities in Science, Technology and Innovation,” says Domenica Blundi.

ITV acts to expand research and technical competence

The Vale Institute of Technology is one of the pillars of Vale’s research, development and innovation model, established through the creation of the Technology and Innovation Executive Management in 2009. It is a nonprofit institution with shared governance, which takes into consideration the cycle of scientific production, its practical application and the generation of concrete benefits for society.

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TV’s two branches have different profiles, in line with local characteristics. ITV Sustainable Development is in Belém, Pará, and its activities are focused on research into applied computing, environmental technology; environmental genomics; environmental geology and water resources; biodiversity and ecosystem services; and socioeconomics and sustainability. ITV Mining, located in Ouro...
External cooperation begun in 2010 gave rise to the biggest agreement ever signed between the private sector and state research support agencies in Brazil

We have developed a database that could become a management tool for operators.

The two scientific directors define the roles of ITV’s two branches as follows:

“We are looking for innovation, but with theoretical foundations. As well as spreading knowledge, we are encouraging people to grow, study and improve their performance. By investing in ITV, Vale is training professionals who find a balance between technical and scientific studies and deliveries,” says Laurindo Leal.

“Our strategy is to do high-quality research while we solve significant problems for the company – sums up José Oswaldo Siqueira.

Siqueira stresses the pioneering nature of ITV’s work in Belém, including basic studies of the botany and biology of Carajás: “No other mining company anywhere in the world is investing in this.”

When it comes to entrepreneurship, both ITV branches are helping to incubate startups that could provide services or products of interest to Vale’s operations or society as a whole. “ITV Mining has been making major efforts to promote the future of the Iron Quadrangle region of Minas Gerais. The mineral deposits there are finite, but mining skills will remain and turn into enterprises. We already have two companies in the incubation phase,” states Leal.

Sandoval Carneiro, executive director, ITV

Pioneering master’s program

ITV’s branches also operate in the areas of education and enterprise. In the first area, they run specialization courses for Vale employees and professional master’s programs, which are also open to external researchers. Recognized by the Brazilian Ministry of Education Agency for Graduate Education Support, CAPES, this master’s course is the first of its kind to be provided by an institute linked to a mining company.

“We want to bring a technological and academic vision into our operations, while providing the institute with a more realistic perspective. It is important to expand the company’s knowledge and technical competence,” says José Oswaldo Siqueira, the scientific director of ITV Sustainable Development. Laurindo Leal, ITV Mining scientific director, notes that “interaction with the productive sector has been very interesting. There are good synergies between professionals who have innovation in their DNA and people who understand our business in depth.”

When it comes to entrepreneurship, both ITV branches are helping to incubate startups that could provide services or products of interest to Vale’s operations or society as a whole. “ITV Mining has been making
The expression “open innovation” was coined in 2003 by Henry Chesbrough, a professor at the University of California in the United States. By authoring the book “Open Innovation: The New Imperative for Creating and Profiting from Technology,” he launched the concept that companies need to take the external environment into account when generating innovation. Collaborative in essence, open innovation first became part of Vale’s culture in 2009, when the company set up the Vale Institute of Technology (ITV) Department, which would later become the Technology and Innovation Executive Management.

“The idea of open innovation is aimed at sharing, teaching and learning. The more open you are, the more knowledge you receive,” explains Domenica Blundi, a technical specialist in Science and Technology Cooperation and Project Monitoring.

Developing Science and Technology regionally

Based on this principle, over the last eight years Vale has entered into partnerships with research support foundations in six states and various universities, including the University of São Paulo (USP), Federal University of Minas Gerais (UFMG), Federal University of Pará (UFPA), State University of Campinas (Unicamp), Federal University of Ouro Preto (UFOP) and Federal University of Juiz de Fora (UFJF), among other institutions. Out of Vale’s relations with the Science and Technology community, Research and Development projects geared toward the company’s medium and long-term interests have arisen. Another positive effect has been the regional promotion of scientific and technological development in locations where the company operates.

“Engaging in open innovation means understanding that, despite all your internal competencies, there will never be enough of them to extrapolate your activities. So, if you want to innovate, you need to interact and collaborate with other organizations,” says Blundi.

Open to risk

According to Luiz Mello, Vale’s executive manager for Technology and Innovation and ITV’s chief executive officer, open innovation presupposes that companies and people are open to risk. In Vale’s case, 20% to 30% of total Research and Development investment goes to high-risk ventures.

“Open innovation in Brazil is still a work in progress. Society is gradually realizing that having an idea is good, and if ideas can be patented, it is even better. But the subsequent stages imply continued investment by people,” Mello says.

In the view of Cristina Assimakopoulos, an analyst who specializes in Technological Development in Vale’s Technology and Innovation Executive Management, the phrase that best applies to Vale, in line with the concept of open innovation, is: “Not all the best things and people are to be found at my company.” She believes that open innovation is a model in which everyone wins, as it allows the extensive sharing of knowledge and resources, as well as internal and external recognition.

Humberto Luiz de Rodrigues Pereira
President of the National Association for Research and Development at Innovative Companies (Anpei), of which Vale is a member

What is the role of open innovation for the development of research?
It is a very powerful mechanism, although it is not the only one. It is a manageable process, which entails a different vision of intellectual property. It works for companies and other institutions, like universities.

What profile must professionals have to work with open innovation at a company or institution?
The profile of a promoter. This model requires people with the capacity and willingness to ask questions and take on challenges.

How does Anpei work to promote investment in innovation?
Anpei acts in three areas: institutional, technical and networking. It promotes the process and stimulates innovation, seeking public and private sector resources, besides working directly with the government to improve the legal framework and reduce bureaucracy.

What are the obstacles to progress in this area in Brazil?
We need to create an environment of trust, featuring rules that incentivize collaboration, and to increase the number of researchers.
“We observe that Vale is of great interest to researchers, because they want to do all kinds of tests here, in our actual operations,” says Assimakopoulos.

**Leveraged resources**

For Vale, besides sharing knowledge and risks, working based on the concept of open innovation enables to leverage research investments, given that partners also invest significant amounts of resources in initiatives. It is also possible to use tax incentives. Following the enactment of Law 11,196 of 2005, the company has had the opportunity to use a proportion of the corporate income tax it owes on Research and Development.

“Under this law, a proportion of the amount invested in some kinds of Research and Development projects can be recovered. The main advantage of this law is the ability to deduct 60% of expenses on eligible projects from income tax. If a project generates a patent, an additional 20% of expenses or payments linked to its development can be deducted. Another benefit used is exemption from withholding income tax on payments abroad assigned to apply for and maintain patents. In recent years, the amount of tax saved through this law has been growing, representing approximately 5% of Vale’s annual investment in Research and Development,” explains Geraldo Barbosa, an engineer in the company’s Partnerships and R&D Area.

As of 2016, the Technology and Innovation Executive Management was coordinating 24 projects under development abroad and 171 projects in Brazil. In all, 84% of these initiatives involved partners. And the benefits of these arrangements are not restricted to Vale and its partners: the legal and cultural framework for the Research and Development Area is advantageous to the country, as it serves as a base for other companies to adopt the model and feed a virtuous cycle, in which there is a constant drive for better results.

“I am proud to see the returns that Vale is generating. Progress in knowledge is a legacy,” Assimakopoulos says.
In a world where collaboration is key to improving processes, it is essential to develop best practices, innovate and maintain productive, high-quality partnerships. The Technology and Innovation Executive Management has held several Calls for Proposals since 2010, thereby expanding Vale’s portfolio of partners and generating structured, long-term cooperation in Research and Development.

According to Luiz Mello, the Area’s executive manager and the chief executive officer of the Vale Institute of Technology (ITV), working with the concept of open innovation provides the chance to improve the allocation of resources, among other benefits: “It is possible to choose the most promising opportunities, without putting effort or money into initiatives that have already proven to not be worthwhile.”

Sandoval Carneiro, a technical specialist in Partnerships and Resources at Vale and ITV’s executive director, says that there are open innovation projects under way in Brazil and abroad. In 2016, thanks to a partnership between the company, the National Council for Scientific and Technological Development (CNPq) and Canadian research organization Mitacs a Call for Proposals for post-doctoral fellowships in Canada was open to candidates who had earned their PhD up to five years previously.

“We have 10 Brazilians developing research in Canada. The themes selected for this public call include geoscienc; the environment, mining, engineering and geology,” explains Carneiro.

In 2015, a partnership with CNPq was structured, giving rise to CNPq/Vale/ITV Call for Proposals 13 of 2015, through which 65 researchers were selected to work on research projects at ITV facilities in Belém and Ouro Preto. Once engaged in the projects, the researchers were given scholarships in line with the research area. They have the status of resident researchers at ITV and they may receive a specific certificate when they complete their work.

Between July 2016 and March 2017, Vale and the Brazilian Ministry of Education Agency for graduate education support, CAPES, agreed to offer 20 postdoctoral fellowships to researchers who were interested on topics related to mining and sustainable development. In addition to monthly stipends of R$7,000, a R$10,000 bench fee was given to each project coordinator.
Interaction between company and universities

Vale signed an agreement with the research support foundations of São Paulo, Minas Gerais and Pará (Fapesp, Fapemig and Fapespa, respectively) in 2009, and the Calls for Proposals were published in 2010. The first projects began in 2011, using R$61 million of funding from Vale and R$38 million from the foundations. The partnership with Fapesp has funded 24 projects and 105 research scholarships at nine Science and Technology institutions. The partnership with Fapemig has funded 56 projects and 163 research scholarships, involving 17 institutions. The partnership with Fapespa has supported 34 projects and 353 research scholarships, distributed among four higher education institutions.

In the case of Minas Gerais, many of the projects have the potential to be used by Vale in its mining operations. Regarding this practical application, Paulo Sérgio Lacerda Beirão, Fapemig’s Science, Technology and Innovation director, argues that the publication of a scientific paper is important, but there is not much point if the knowledge is restricted to bookshelves. The results of research need to be absorbed outside academia, whether at private sector companies or in the public sector.

“One way to do this is to tackle major issues that companies present, to identify the technological or knowledge bottlenecks that are impeding innovation – says Beirão.

Elza Fernandes de Araújo, Fapemig’s Innovation assistant advisor, agrees with Beirão, noting that interaction between universities and companies is vital:

“A large share of accumulated knowledge lies in research institutions such as universities and Science and Technology institutes, which master a given methodology or have made progress

Focus on structured, long-term cooperation

Channel to receive R&D proposals

Vale’s Technology and Innovation Executive Management evaluates R&D projects submitted by institutions that are interested in forming partnerships with Vale. The channel is activated when a Call for Proposals is published or a new research area is planned.

On a form posted on www.vale.com, on the Global Opportunities page, both external stakeholders and employees can submit proposals, providing that they contribute to meeting the mining chain’s challenges in the medium or long term. They must also address at least one of the 10 themes considered strategic to the company: Health and Safety; Tailings Dams and Waste Management; Productivity; Caves and Rocky Outcrops; Moisture and Dust; Communities; Automation; the Environment; Conveyor Belts; and License to Operate.

When filling in this form, candidates must specify the estimated budget for the project. Vale’s investment may be applied following the same funding modalities used by research support agencies: scholarships; long-term materials (technological resources and equipment to execute the project, whether produced in Brazil or imported); consumables (materials or inputs used to execute the project, whether produced in Brazil or imported); participation in conferences; field research trips; and third party services.

The evaluation cycle for the submitted projects is annual and split into two phases: technical, in which the strategic and technological aspects of the proposal are analyzed; and budget, in which the availability of corporate resources for investment the following year is verified. If and when all the requirements are met, a cooperation agreement between Vale and the partner institution is signed.
in an area of knowledge. If a company is not aware of this, it misses an opportunity to meet a demand or solve a problem, often in a fast and relatively easy way. When researchers work directly with corporate demands, they get a better understanding of the needs of the company and they obtain more robust results. I think it is admirable that all of Vale’s technical staff are striving to advance in this direction.

Regional development

Eduardo da Costa, the CEO of Fapespa, emphasizes the importance of research associated with local education institutions for regional development. “I have no doubt that investments in Science, Technology and Innovation help us to think about the new economy, social technologies, vertical production and the diversification of employment and income. In this area, Vale has played an important role in promoting the development of Para,” he says.

Vale is also working with the research support foundations of Rio de Janeiro, Espírito Santo and Maranhão (Faperj, Fapes and Fapema, respectively). With Fapes and Faperj, for example, 43 research projects in the Areas of the Environment, Pelletizing and Logistics have been funded to the tune of R$15.32 million. In each agreement, Vale has matched the investment made by the foundation: regarding Faperj’s agreement, both parties contributed R$3.95 million, whereas in the agreement with Fapes, they both invested R$3.71 million.

All the partnerships held since 2010 have encouraged the formation of research networks between higher education institutions in the states involved, and have led to the promotion of cooperation between researchers, and this has further improved the quality of the projects and has intensified the sharing of knowledge. In the public Calls for Proposals held with the Rio de Janeiro and Espirito Santo foundations, 18% of the projects have been developed as part of a network.

Other partnerships

Vale and the National Council for Scientific and Technological Development (CNPq):

**Mining Sector Fund**

Top-priority project themes:
- Technology Trends in the Mining Sector and Technologies for Local Mining Sector Production Systems.

**Start:** 2009  
**Period:** 36 months  
**Investment:* R$6.90 million – R$4.70 million from Vale and R$2.20 million from CNPq, through the Mining Sector Fund

**Engineering Training Program (Forma-Engenharia)**

This program offered scholarships to high school students and engineering undergraduates to work as part of a team on science projects and to stimulate their interest in choosing engineering courses.

**Start:** 2011  
**Period:** 18 months  
**Investment:* R$24 million – R$12 million from Vale and R$12 million from CNPq

*Referring to the amount invested by Vale, according to cooperation agreements established with the partners.

Vale and Brazil’s national development bank, BNDES:

In partnership with the University of São Paulo, Vale is sponsoring a bioremediation research project to economically exploit waste materials generated in copper processing.

**Start:** 2012  
**Period:** 72 months  
**Investment:* R$15.18 million – R$3.09 million from Vale and R$12.09 million from BNDES

*Referring to the amount invested by Vale, according to cooperation agreements established with the partners.
The Cátedra Roda-Trilho (Wheel-Rail Chair) is a university research chair for investigating the wheel-rail contact phenomenon, set up in 2014 based on an agreement between Vale (Railroad Engineering Management, and Technology and Innovation Executive Management) and the University of Sao Paulo (USP) Polytechnic School, in order to establish a model for collaboration between Brazilian companies and Science and Technology institutions.

Cátedras (Chairs) are academic professorships for teaching and investigation of a topic on a long term basis. The initiative has been led by USP in association with a number of institutions. The research is carried out in cooperation with researchers at the Vale Institute of Technology (ITV), at the Federal University of Espirito Santo (UFES), Federal University of Juiz de Fora (UFJF), Federal University of Pará (UFPA) and State University of Campinas (Unicamp). Each of these institutions has a representative on the Chair Committee which reviews progress reports and defines the next steps to be followed in the research, in conjunction with Vale.

Careful route planning

At present, 15 projects are being developed on the following topics: Wheel and rail metallurgy; Wagon dynamics; Geometry and forces on the permanent way; Permanent way superstructure; and Wheel-rail contact management. Amilton Sinatora, now a tenured researcher at the Vale Institute of Technology (ITV), was a tenured professor in the Department of Mechanical Engineering at USP when the agreement was signed. He said that one of the reasons for the success of the Cátedra was the careful way in which it was structured:

“We were thinking long-term. The first step was to organize events in São Luís (state of Maranhão) and Vitória (Espirito Santo). Teaching staff, suppliers and Vale employees all took part in discussions on Tribology (study of friction, wear and lubrication). This was followed by visits to São Luís to identify study opportunities with Vale technical teams and gradually we transformed this into a number of projects based on the requirements and skills involved.”
According to Amilton, there were no communication problems between researchers and Vale professionals. From the onset interaction was fairly positive and the greatest challenge, now overcome, was finding a legal instrument capable of protecting the interests of the company, the creative freedom of the professor and the intellectual property of discoveries made during the projects.

Two-way knowledge exchange

Engineer Aldo Machado, a specialist in Railroad Management, was one of the Vale professionals who supported the activities of the Chair. He has worked at Vale for six years and affirms that “one of the interesting aspects of this model is seeing how projects developed at different universities can complement each other. Furthermore, working with Brazilian institutions is very practical in terms of proximity. Universities are here-and-now institutions, but they will still be here in ten years. Researchers can learn from our operations and our professionals learn from the technologies developed by the academics. It is a two-way track allowing knowledge to be retained and deepened, something that is difficult when working with foreign consultancies, for instance.”

High-speed results

Mechanical engineer Roberto Souza is currently the project coordinator and teaches at the Department of Mechanical Engineering of the USP Polytechnic School. He studied for his doctorate in Materials Engineering and Metallurgy in the United States, and has been a post-doctoral fellow in both Brazil (USP) and France.

He has been Cátedra coordinator for a year and has identified some other advantages of joint research: “The conventional model of corporate research has its benefits, but it is difficult to ‘move sideways’. It takes longer for professionals at these centers to obtain their qualifications. If the company contacts a university that is already engaged in research of interest, this saves an enormous amount of time, so results and solutions are achieved much faster. As far as we academics are concerned, it is an opportunity to put theory into practice for the benefit of society, and to continue advancing in our academic careers but obtaining further qualifications.”

As projects are developed (see the table below), it is hoped that the knowledge acquired will result in improved vehicle safety, increased load capacity per axle/wagon and durability for the railroad network. These parameters are important to the competitiveness of Vale’s logistics services. In this edition, the newsletter details two initiatives under the umbrella of the Cátedra Roda-Trilho in order to clarify the dynamics of the research model, as well as publishing the initial results of research projects under way.

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<th>Project</th>
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<th>Institution</th>
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<td>Characterization of welds and regions affected by the weld in various types of rail used by Vale, and creating a model for the prediction of the desired properties of the weld and the region affected by it</td>
<td>2016</td>
<td>Luiz Henrique Dias Alves</td>
<td>UFJF</td>
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<td>Contact mechanics: preparation of shakedown diagrams and their application to wheel-rail situations</td>
<td>2016</td>
<td>Cherlio Scandian</td>
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<td>Models of mechanical contact between wheel and rail for heavy haul railroads</td>
<td>2016</td>
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<td>Study of the frame brace structure on a railroad wagon</td>
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<td>Study of rail defects</td>
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<td>Analysis and definition of wheel and rail profile design criteria, taking account of vehicular dynamics and how they are related to manufacturing processes</td>
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<td>Guilherme Fabiano</td>
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<td>Factors leading to faults such as ovalization and fracturing in wheels used in Heavy Haul scenarios</td>
<td>2016</td>
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<td>Defects in railroad wheels</td>
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<tr>
<td>Support for the deployment of preventive grinding of rails on the Vitória to Minas Railroad</td>
<td>2017</td>
<td>Roberto Martins de Souza</td>
<td>USP</td>
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<tr>
<td>Catalog of defects in crocodiles</td>
<td>2017</td>
<td>Roberto Martins de Souza</td>
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<td>Support for the creation of a rail quality index: contribution of mechanical properties, contact fatigue-resistance and thermal stability of the microstructure</td>
<td>2016</td>
<td>Hélio Goldenstein</td>
<td>USP</td>
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<td>Lubrication</td>
<td>2017</td>
<td>Tiago Cousseau</td>
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<td>Wheel microstructure</td>
<td>In processing phase</td>
<td>Paulo Roberto Mei</td>
<td>Unicamp</td>
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Contact model is world class innovation

Titled “Models of mechanical contact between wheel and rail for heavy haul railroads”, a promising research project has been underway since 2016, headed by professor Alfredo Gay Neto, at the USP Polytechnic School, in partnership with Vale’s Railroad Engineering Area. The objective is initially to understand how the existing contact models are structured in the Nucars and Vampire systems, used by Vale. On the basis of the results, researchers will formulate and implement new contact models for representing the wheel-rail interaction, based on determining the contact forces and using a master-master formulation, an innovation in railroad applications.

The scope of the project also encompasses a study to determine the distribution of contact pressure over the wheel-rail geometry. In addition, the jolts caused by slight vertical misalignments between sections of railroad rail will also be investigated.

Tracking down discoveries

Alfredo Gay Neto graduated in Mechanical Engineering from USP, where he has also studied for his doctorate. He was a post-doctoral fellow at the USP Polytechnic School and at the University of Leibniz in Hannover, Germany, and his thesis was titled “Computational contact mechanics between beam structures”. In his research at Vale he works with two master students and three undergraduates studying specific topics within the project.

“When transporting 35 tonnes of ore on wheels, each wheel has to withstand 17.5 tonnes over a contact area with the rail of approximately 1 cm². As the train moves along, it contacts a different point on the rail with constantly changing pressure on both wheel and rail. This cyclic stress causes fatigue and can result in cracking, for instance. The materials can also suffer wear during this wheel-rail interaction. The important question is: how many times can the train pass over the rail before it breaks?” Alfredo explained, shedding light on the objective of his research.

The answer, based on an understanding of the physics of the phenomenon that leads to fatigue and wear, will help prevent accidents and result in early rail repair. One of the lines of study, developed by USP master student Debora Naomi Higa, is more pragmatic in this respect and seeks to optimize the rail surface. Based on an assessment of the procedure implemented throughout the world, the study objective is to find more adequate rail and wheel geometries to deal with the diverse conditions under which loads are transported, defining, among other things, the rail shape to be milled to obtain the best results. “These parameters are nowadays passed on by consultancies under contract. Our research aims to provide Vale with acquired knowledge, and the company will then be able to use its own specialist skilled labor,” said Alfredo.

Leading-edge research is the driving force

A second research topic is a pioneering approach proposing a new way to deal with wheel-rail contact, based on a contact model developed by Alfredo Gay Neto over the past two years, in partnership with the University of Hannover, and so far unused in railroad applications. “It is really innovative. Vale is investing in leading-edge research,” he said. The model works in conjunction with the Finite Elements Method, used to calculate relocations, deformations and tensions in a structure subjected to loading and restrictions.
Paulo Roberto Refachinho de Campos, a master student at USP, is involved in the research and will write his dissertation on the topic. In July 2017, at the 5th International Conference on Computational Contact Mechanics in Italy, he presented a paper on his work as a researcher to date. He presented a schematic of the conceptual model proposed and pointed out how promising it looked. In figure 2, rigid bodies linked to parametrized conical surfaces are used to represent the wheels that interact with the rail. The rail is modeled by beam finite elements.

As well as the research submitted for his master’s degree, the stages still in development today include:

- parametrization of the wheel and transverse section of the rail, in accordance with geometric specifications defined by Vale based on the typical profile of the wheels and rails used in the operations of the company;

- modeling the general equation of the movement of a rigid body by means of six degrees of freedom (three components of translation and three of rotation). The model will be defined as a function of the inertia matrix of the wheel, computed by auxiliary CAD software, generating input data for the Giraffe program run at USP and developed by Alfredo Gay Neto;

- modeling of wheel-rail contact, the main innovation in the project, which should predict the possibility of point contact with one, two or three points of contact, and capture the rotation of the wheel on the rail, as well as the possibility of skidding during braking or at bends.

Once the implementations of the new contact models are completed and post-processed, it will be possible to generate a set of simulations and results to study the sensitivity to the predicted contact pressure in relation to the geometric parameters of the wheel and rail profiles. Thus it will be possible to establish a methodology to choose suitable profiles for the wheel-rail pair based on the maximum contact pressure criterion. In future, other criteria will also be established.

“In time we will be able to couple contact forces with wagon dynamics, comparing the proposed new model to the current outsourced model, in order to assess which of them is the most advantageous. Doing this work from scratch will give Vale total control over the process and will also be useful to define future study topics. At our meetings with Vale teams, we were able to talk about practical issues, such as the locations at which the most intense fatigue occurs, enabling us to appreciate the problem from a different perspective. This helps a lot in finding a solution,” said Alfredo.

Engineer Edilson Jun Kina, a technical specialist on Rotating Material in the Railroad Engineering Management, has worked at Vale since 1993 and is a key player in a number of Cátedra Roda-Trilho subprojects. He had this to say: “The level of discussion was very high during talks with the researchers. Even our conversation with the suppliers changed. On the one hand, we have the opportunity to build our team’s capacity and on the other to provide advanced training for the young people who will enter the jobs market with in-the-field knowledge, fully prepared.”
Mathematical model will boost weld quality

In the wheel-rail interaction studied within the framework of the Cátedra, welds along the railroad track are a key factor in the safe transportation of people and ore, resulting in higher operational productivity, given that every year 5,000 to 6,000 aluminothermic welding operations are carried out on the Carajás Railroad (EFC) alone.

To improve process performance and meet the high existing reliability standards at Vale, a research project titled “Characterization of welds and regions affected by the weld in various types of rail used by Vale, and creating a model to predict the desired properties of the weld itself and the region affected by it” has been under way since 2016.

The project is a partnership involving Vale’s Railroad Engineering Area, and is headed by professor Luiz Henrique Dias Alves of the Federal University of Juiz de Fora (UFJF), who graduated in Metallurgical Engineering from the Fluminense Federal University (UFF), studied for his master’s degree in Mechanical Engineering with specialization in Materials, Tribology and Surface Phenomena at the University of São Paulo (USP) and for his doctorate in Mechanical Engineering at the Júlio de Mesquita Filho State University (UNESP).

Welding course and participant engagement

Within the Cátedra, and even before the project was formally inaugurated, Luiz Henrique set up a rail welding course in São Luís (state of Maranhão), that he administered with professor Móises Lagares (UFJF), attended by 25 Railroad Engineering professionals active in the field, including the welders themselves.

Two months after initial contact with the researchers during the course, in October 2015, Vale reviewed the welding procedures at EFC. This initiative brought concrete results based on the adoption of measures such as increasing the time allowed for the removal of clips and the base plate from 4 to 5 minutes, and the weld deburring process from 6 to 7 minutes.

“I have never administered a course in which the participants were so engaged. They asked questions and wanted to clear up their doubts and queries. On the following day, I continued to receive requests by email and since then I receive phone calls from Vale employees whenever they want to know something. It is a really good interaction, and very important for our research,” said Luiz Henrique.

Ricardo Souza, an engineer in the Railroad Engineering Management that provides support to the study, remembers that the course, also offered in Vitória, “introduced the teams handling the day-to-day activity of welding to a theoretical, scientific view of their work. We realized that with this knowledge, welders could understand why they were carrying out the procedure in a specific way. And understanding the process in theoretical terms is fundamental to the success of the practical application.”
From São Luís to the international conference

At the beginning of the project in 2016, the team observed rail welding in the field and in the Vale welding plant workshops, collecting samples of welded joints. After taking note of all the welding parameters used and the cause-and-effect relationships affecting the welded joint, the researchers were able to fully characterize the joints in terms of microstructural variation, dilution area, chemical composition, hardness, mechanical properties and internal health.

So far, the study has covered aluminothermic rail welding processes and moved on to study spark welding. The research was conducted on a test line laid beside the EFC Line in São Luís, and the processes studied are described in a paper titled Employing the Design of Experiments for Optimization and Modeling of Thermite Welds of Rails Used on the EFC Line, presented in September 2017 at the International Heavy Haul Association (IHHA) Conference in South Africa. The text was written by professors Luiz Henrique and Roberto Malheiros, also teaching at UFJF, and by Vale engineers Aldo Machado, Ricardo Souza and Raimundo Baldez, from the Railroad Engineering Management.

Thermite process in detail

The various stages in the thermite welding process used at Vale were examined. It is a fusion welding process in which the heat required is produced by a highly exothermic aluminothermic reduction reaction, with temperatures reaching over 2500°C.

The advantages of thermite welding are short lead times and good quality welded joints, but the number of variables involved can lead to defects related to solidification, such as suckbacks, microsuckbacks, porosity, segregation, cracks and other metallurgical defects that impact the mechanical properties and hardness of the weld and the zone affected by the heat produced.

Materials and methods

To examine the effect of each factor involved in the thermite process and possible ways in which it can be affected by variations in other factors (i.e. interactions), the Design of Experiment (DOE) method was used. Its objective is to determine how the variables affect the process with the expected degree of precision and at the lowest cost.

The variables to be investigated in the analysis were defined in conjunction with the EFC technical staff, based on the eight alternatives documented in the literature, opting for the three that are more...
Master-master formulation: Technique for computational processing of contact models in which both contact candidate surfaces are treated equally and there is no a priori choice of material points that are candidates for contact with one of the two sides (slave points). This is exactly how it differs from the master-slave technique.

Finite Elements Method: Numeric method with great potential in computational applications, allowing an approximate solution for differential equation systems. In practice, it can be used to solve structural mechanical models, in fluid mechanics and in various other important engineering applications.

Wheel inertia matrix: In describing the wheel as a rigid body, the distribution of its mass in space can be represented by a single mathematical entity called an inertia matrix containing all this information. This matrix is fundamental to study the dynamic behavior of the wheel.

Suckbacks: Internal weld defects caused by the solidification process. They occur as a result of natural contractions during the transition from the liquid to solid state.

Full factorial: Experimental model in which all possible combinations are represented.

Risers: Also known as “feeders”, they are welding reservoirs positioned at rail sections to feed liquid to compensate for solidification contractions, thereby avoiding the formation of suckbacks in the part or weld.

Deburring: Removal of burrs or feed channels and risers. A rough finishing operation.
Amilton Sinatoria

Curiosity and method are the baseline for training a researcher

Q ualified metallurgist professor Amilton Sinatoria graduated from the University of São Paulo (USP) Polytechnic School in 1975. He studied for his master’s degree and doctorate at the State University of Campinas (Unicamp), and was a post-doctoral fellow at the University of Bochum in Germany. As a tenured researcher at the Vale Institute of Technology (ITV) since 2016, Amilton played an active role in conceiving the Cátedra Roda-Trilho as project coordinator at USP. In this interview, he talks about his professional background, research at Vale and the importance of knowledge sharing between the company and the academic world.

In each locality, there is a need to strengthen local Science and Technology institutions, so that they have the capacity to provide the company with qualified people, and social and technological services, as well as innovation and research in their fields of interest.

Where did you work before joining the Vale Institute of Technology (ITV)?

At the São Paulo Technology Research Institute, at Mackenzie University and Mauá Engineering School, and in the Department of Mechanical Engineering at the USP Polytechnic School, where I taught for 31 years. I was also Innovation Manager at Villares Rolls (cylinders for steel rolling mills), a company now part of the Gerdau Group.

Do you now work exclusively for the ITV?

My activities include advising doctoral students on the Postgraduate Program in Mechanical Engineering at USP and on the professional master program in Automation at ITV Mining, in Ouro Preto.

What lines of research are you pursuing?

My own line of research is Tribology (study of various kinds of wear, friction and lubrication). My research at USP and also at ITV is focused on the following topics:

• wear in mining, within the framework of a project on milling bodies (mill balls) aimed at finding lower cost materials;
• wear on conveyors, centered on plates for covering chutes and recently-inaugurated projects on rollers, and a project on belts that is in the preparatory stage;
You need to formulate a good question, prepare a critical experiment that tests the hypothesis, analyze the results criticizing both the method and the hypothesis and press on, either gleaning the benefits or preparing and testing new hypotheses.

In your opinion, what does it take to be a good researcher?

Curiosity and method. Curiosity is essentially innate and is associated with a constant disquiet regarding the state of things. Method is learned, and studying is part and parcel of it. You need to formulate a good question (hypothesis), prepare a critical experiment that tests the hypothesis, analyze the results criticizing both the method and the hypothesis and press on, either gleaning the benefits or preparing and testing new hypotheses.

What motivated you to follow this path?

My father was exemplary when it came to curiosity, and his father, my grandfather, had a love of studying. I was privileged to study at a high-quality public school, the Paraná State College, where I was inspired by a science teacher in first grade, and I had access to a well-stocked library with books in various fields. In addition to the school library, the Curitiba Municipal Public Library was on my way back home.

What legacies should a researcher leave to society?

A researcher is an employee of a company or the State. For this reason, his or her obligation is to carry out the task at hand. In my case, it is to cut losses due to wear at Vale, increase plant availability, etc. Since my tribology research was aimed at reducing material consumption and energy loss by friction, and minimize the use of lubricants, I indirectly made a contribution to the environment, which is almost inevitable. This seems important to me, and it was for this reason that I chose tribology as my field of activity. Almost always it’s possible to benefit the company and simultaneously the society.

This would be the ideal scenario, would it not?

Science is committed to dominant values in each period of history and in each country where science is encouraged and supported. In my opinion, a researcher, like any other citizen,
should be constantly critical, not just in the laboratory but also about life in general. That is why I think that the greatest legacy, in addition to the strictly professional contribution, is a critical attitude and constant questioning. Finally, there is the contribution that embodies all the above: educating people and future generations of scientists. I am proud that some of my former post-doctoral students have achieved a lot more than I had at their age, both in their specific activities and in regard to their critical attitude.

How would you rate the importance of innovation open to interaction between the corporate and academic worlds?

Open innovation, innovation in partnership with Science and Technology institutions in Brazil and sometimes abroad, as well as innovation with companies in the supply chain, are ways to achieve innovation, but there are many others. Depending on a country’s immediate situation, that of its companies and especially Vale, the use of innovation may or may not be appropriate. Today I think it is fundamental, since Vale’s mines are where they are and for this reason, in each locality there is a need to strengthen local Science and Technology institutions, so that they have the capacity to provide the company with qualified people, and social and technological services, as well as innovation and research in their fields of interest. In addition to this strategic need for both Vale and Brazil at this time, there are obvious benefits for the company, which is able to consult an enormous amount of knowledge in the Brazilian public research system and make use of this knowledge, whether in-company or by interacting with academic institutions, in solving problems or anticipating business needs.

How would you rate this interaction in general today in Brazil and specifically at Vale?

Today Brazil has a vast network of well-equipped laboratories and a fairly substantial force of engineering researchers. At present, there are problems in funding these laboratories. At the same time, although significant advances have been made, the commitment of these researchers is still limited in regard to topics that are of national importance. Overcoming these limitations makes the role of ITV and Vale much more motivating and important. Although I have only been working at ITV for a year, I can see that Vale has begun to realize that research, just like work and capital, is a factor in production, and one of the factors that can make a difference: In this sense, mobilizing for innovation and closer links between the mining departments and Vale Institute of Technology are encouraging signs.
Fragcom seeks high-performance, low-cost blasting

Fragcom is a research project developed by the Technology and Innovation Executive Management at Vale, in partnership with the Operations Directorate at Ferrosos Sul/Sudeste and the Mineral Research and Mining Planning Laboratory at the Federal University of Rio Grande do Sul (UFRGS). The idea was inspired by a similar initiative in Australia during the 1990s, the Mine to Mill project, which commenced in 2012 with a broad spectrum of objectives: to study the fragmentation produced by blasting rocks using explosives, and its impacts on mining and comminution operations. Because of its extensive nature, it turned into a number of subprojects related to Planning, Drilling, Blasting, Loading, Transportation, Sampling, Crushing and Milling.

How Vale found out about this project

The Fragcom proposal was made to Vale by professor Jair Koppe, who graduated in Mine Engineering from the Federal University of Rio Grande do Sul (UFRGS) and in Geology from the Vale do Rio dos Sinos University (Unisinos), with a master’s degree in Civil Engineering (Soil Mechanics) and a doctorate in Geosciences from UFRGS. He was a post-doctoral fellow at the University of Queensland, which led to the development of the Mine to Mill project in collaboration with Australian mining companies.

“I raised the subject of Fragcom and discussed it with Vale following a request from the company stating their wish to understand how to evaluate the costs of drilling and rock blasting operations. Our laboratory staff have been collaborating with Vale for many years. When we submitted the project for the first time in 1998, the company rarely used explosives in its operations; the ore was extracted basically by mechanical excavation. Much later, at the beginning of this decade, Fragcom was rendered viable when Vale built a facility for processing compact itabirites in Itabira (state of Minas Gerais). The projection was that hard rock mining would grow by up to 80% over the next few years, so the entire operation will need adequate fragmentation to satisfy the plant’s needs. This is also the case at other mines owned by the company,” said Jair Koppe.

Opportunity for technical capacity-building

After the diagnostic phase, aimed at making the Fragcom study more productive in the various areas of knowledge involved, a professional master’s degree was created to explain the project to technical employees at Vale, enabling them to help in the research work and, at the same time, participate in all its phases. In 2013, after taking in-company courses, 17 staff members of the Ferrosos Sul/Sudeste Operations Directorate were able to undertake research related to their particular fields: “Our research team joined forces with very important company sectors in order to develop Fragcom, with everyone working together on the project and making a contribution,” said professor Koppe.
Overview of the process

The 14 subprojects currently under way are interrelated and in line with the final objectives of the research, which provide a detailed analysis of all the stages of the fragmentation process. For instance, studies are being undertaken on integrating the geological blasting model, the ideal number of holes for blasting, identification of compact blocks using geophysics, optimizing the use of blasting drillholes, reducing fixed loading and transportation times, minimizing load transportation bottlenecks and cutting mill energy consumption.

The aim is to achieve high-performance, low-cost blasting based on an assessment of topics such as the impact of fragmentation on comminution operations and the variables that most affect the crushing and milling line.

Promising initial results

In practice, it was concluded that increasing the number of explosives drillholes to be detonated simultaneously led to higher productivity and reduced the need for excavator maintenance due to reduced relocation on site. It was also noticed that it was possible to achieve greater efficiency in defining the drillhole pattern and determining where to place each type of explosive and in what quantity, based on geological and geophysical models, in order to obtain the best results.

At present, four master’s dissertations by Vale professionals are in the final stages of development, and are to be presented in 2017. Two dissertations have been completed and a further ten are scheduled for completion in 2018. Engineering papers written by Vale and UFRGS have already been published in scientific journals and presented at events such as the 2016 World Mining Congress in Rio de Janeiro.

Two of the 14 research subprojects relating to Geophysics and Transportation are discussed in this edition. They are sufficiently advanced to give a clear picture of how Fragcom is developing.
Research cuts fixed transportation time

Loading and tipping cycles for transportation of extracted ore and sterile material between the mine face and primary crushing and/or sterile deposits pile are determined in terms of the trip from loading point to tipping point, and subsequent return to the loading point. This cycle, usually measured as the time elapsed between two successive loading operations, comprises fixed and variable times.

Fixed times are those related to loading, handling and tipping for the transportation fleet and loading plant, forming the productive cycle (queuing for loading, handling time, loading time, queuing for tipping and tipping time), whereas variable times are linked to the average speed of the trucks and the distance travelled.

With the aim of cutting fixed times in the production cycle, a rarely studied variable but representing 10 to 13% of fleet productivity, the research on the “Influence of fixed times on transportation fleet productivity” was included in the Fragcom project. This topic has been investigated since 2014 by engineer Rodrigo Lisbôa, under the supervision of professor Jair Koppe of the Federal University of Rio Grande do Sul (UFRGS).

Rodrigo has been with Vale for 19 years, is manager of Itabira Mineral Complex Operations where the study was conducted, and his work was documented in a master’s dissertation. Even before its conclusion, research was already under way and had produced concrete results, including a drop in fixed times of around 10% in 2016 compared to operations in 2014.

Productivity calculation

“For transportation plant, productivity is measured in terms of the tonnage transported during each effective hour of operation. Off-road hourly productivity for trucks is directly proportional to the average load transported and inversely proportional to the fixed and variable times and the distance travelled,” informed Rodrigo.

Theoretical and practical assessments

By analyzing how much impact each of the fixed times has on increasing performance, and cutting durations and operational costs based on existing information in the Vale database, it was possible to link, compare and define the points in the process that needed improving, and thereby draw up a technical ranking of the teams responsible for transportation.

Using statistical tools, the positive and negative impacts on the hourly productivity of each item of transportation and loading plant were identified. The data obtained were used as a basis for training and recycling operators in regard to the positioning of the plant. Theoretical and field assessments produced results that were discussed in order to provide on-site feedback for each operator regarding the issues in question.

“We began training operators every six months, with both theoretical and practical tests. In collaboration with the company responsible for the fleet management system, we created a results integrity indicator to improve plant use. This research gave us a basis for improving the efficiency of day-to-day management, focusing on the way supervision was handled and on characteristics such as the skill or ineptness of the operator,” said Rodrigo.

Other innovative actions

As the research was being undertaken, various innovative actions were implemented in day-to-day operations, including:
Sequential loading

Based on the study of ore transportation, a method of sequential loading was developed for the loaders at the mining face. The procedure allowed off-road truck maneuvers to be anticipated at the loading stations, defining a distance of around 8 meters (width of a CAT 793 mining truck) between vehicles parked for loading.

With an average maneuvering time for trucks at the loader of 58.3 seconds and an average projected time to perform all the steps in the loading cycles of 42 seconds, the difference in these two times (16.3 seconds) represents a real gain for each sequential loading operation.

Tipping

The new practices have cut the tipping distance from 10 to 5 meters, and also the height of the Sterile Disposal Pile (PDE) slope from 10 to 5 meters.

Using this tipping method, around 70% of the load formed the pile at a static angle of approximately 36°, cutting truck tipping times and the cost per working hour of the tractor conveyor. These procedures have minimized the possibility of a collision between the truck and the tractor, have also reduced the risk of the truck falling in the absence of any spatial reference, and have optimized tractor conveyor operations, aimed at increasing productivity by cutting tipping times.

Acceptable load

The maximum acceptable load was reduced from 274 to 264 tonnes while avoiding any negative impact on the average load of the transportation fleet. For two months, all operators...
and clerks were trained and recycled based on this new directive. Constant monitoring and operational interventions were implemented. As from April 2016, gains in fixed times began to appear, as shown in graphic 1.

**Most recent results**

In 2015 and 2016, compared to 2014 there was a net gain of around 23,500 hours in the movements of the transportation fleet, obtained by cutting fixed times and representing an optimization of around 12,700,000 tonnes in total mine transportation. This was a year-on-year saving of 1.21% on the 2015 budget and a year-on-year saving of 2.31% in 2016 (see graphic 2).

According to Rodrigo Lisbôa, the procedures established on the basis of the study titled “Influence of fixed times on transportation fleet productivity” can be generalized to all mines, subject to their specific features, such as loading parameters, lithology, height of pile and type of mining operation. He also reminds that “in the daily routine, in which operational targets are increasingly challenging, the search for ways of boosting productivity and cutting costs safely is a priority. On a mining site, observation and actual experience are the fastest ways of solving problems. However, the work undertaken by postgraduates on the various individual mining operations provides a wider vision of the opportunities, a more critical analysis of the facts that really impact problems, and on this basis, the implementation of planned and structured actions using concepts and formats developed in the academic world. It is now my intention to develop another study for my doctorate”.

To read his dissertation, go to vale.com/MAIS-en.

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**Average load range > 264t x fixed time**

CAT 793 transportation fleet

**Gain in hours (h) and transportation (tonnes)**

Comparison of 2016 and 2015

**Total result of reducing fixed times**
Brazilian iron ore mines are basically seamed formations of iron that have been severely weathered over millions of years. This phenomenon has resulted in deep soil profiles and extensive alterations in the rock profile. In many cases, the compact material has been protected from bad weather, resulting in a mixture of blocks, soil and weathered rock. For decades Vale has been able mainly to use mechanical plants to extract ore, since the decomposed material could be excavated. However, on reaching primary rock, which is increasingly the case, especially in the Southern and Southeastern Systems, the process has required changes, and drilling and blasting with explosives has become essential. Since nature does not simply differentiate friable and compact ores, large compact blocks of ore are frequently encountered in the middle of less dense material. In this case, knowing where to insert explosives and the exact quantities to be used is a challenge that needs to be surmounted, in view of the high costs involved in this work and the potential gains in productivity.

**Beginning of research**

Since 2013, André Vieira, a master engineer in the Ferrous Materials Planning Directorate, has been working within the Fragcom project on a “New approach to planning blasting in severely weathered rock,” using geophysics to seek solutions that will guarantee better blasting results, under the supervision of professors Jair Koppe (Federal University of Rio Grande do Sul - UFRGS) and Marco Antônio Braga (Federal University of Rio de Janeiro - UFRJ). André, who has been working at Vale for nearly seven years, graduated in Mine Engineering from UFRGS and is a doctoral student in Mineral Technology from the same institution, as well as a Master of Science from the Federal University of Pará/Petrobras.

His research was carried out at the Abóboras Mine (state of Minas Gerais) in the Quadrilátero Ferrífero region, the middle portion of the São Francisco Craton, a cratonic core laid down in the Lower Proterozoic. In lithological terms, the Quadrilátero Ferrífero is characterized as a metamorphic complex, represented by a supracrustal sequence of volcanic-sedimentary rocks composed mainly of itabirites, dolomites, philites, quartzites ferruginous rock and ferruginous carapaces. The iron ore (itabirite) occurs in a Paleoproterozoic sequence of chemical and clastic metamorphic rocks. The sequence was severely weathered, with a deep soil profile, a situation that favors the formation of large compact and semicompact blocks of itabirites mixed with friable material.

The yearly iron ore production of the Abóboras Mine has been 21 million tonnes and the study undertaken at the mine is already being implemented in the S11D Elizeu Batista Complex in Canaã dos Carajás (state if Para), where the characteristics are different, but there is compact rock in the form of jaspilites.

“The S11D is an innovative project with no trucks transporting the ore. The granulometry produced by the drilling and blasting process is rigorously controlled, based on the high productivity of the crushing plant. To do this, we created a planning method for blasting the compact rock, based on a 3D geological model integrating geophysical and geological data,” said engineer André Vieira.

**Development of the study**

A study area was selected and, with the visual characteristics of the type of rock found in 14 sections covering 15,000 m², four geophysical methods were applied - electroresistivity, seismic, polarization induced and Ground Penetrating Radar (GPR) – in order to identify the locations of large compact blocks and measure the dimensions of each one.

**Electroresistivity**

Geophysical sections were analyzed to examine the differences in the profile based on magnitude in zones of high apparent resistivity (ZHR), with values higher than 50,000 ohm m, and in zones of low apparent resistivity (ZLR) with values below 2,600 ohm m. Electrical profiles can be examined down to depths of 3 to 30 meters. The data were fairly consistent in differentiating low and high resistivity anomalies. A typical section obtained using this method is shown in the following figure 1.
Induced polarization

The differences in the profiles were examined based on magnitude in apparent zones of high chargeability (ZHC) with values higher than 60 ms (milliseconds), and apparent zones of low chargeability, with values below 10 ms. The geophysical sections showed heterogeneous behavior in regard to the distribution of charge capacity values, as shown in the figure 2.

Seismic

At the study location, 20 geophysical lines were used for low depth seismic refraction, defined by two different horizons based on average seismic velocity. The first horizon showed seismic velocity between 3,023 m/s and 3,417 m/s. The second showed velocities between 3,234 m/s and 3,724 m/s. It was not possible using this method to visualize the base of the layer because the refraction occurred at the higher interface, and no other material with higher density was revealed under the layer.

"We used four methods to obtain efficient results on two horizons. On injecting electrical current, for instance, we can detect zones of high resistivity, represented by hot colors on the graphic produced by the results analysis software, indicating compact bodies. The opposite is true for the cooler colors. The method works for depths of up to 30 meters below the soil with total reliability. Using induced polarization, we know that the longer the energy stays in the solid, the more compact the mineral body is, also represented by hot colors. The convergence of the data produced indicates the best procedure. If we can use lower-energy explosives, there is a significant cost saving," said André.

Integration of geophysical data

The geophysical data were integrated to obtain a short-term 3D geological model of the rock to be blasted (figures 3 and 4). The interpretive geophysical model, validated by ten exploratory drillholes, showed the areas which are predominantly itabirite. A single drillhole is not satisfactory for producing an interpretive geophysical model.

Proposed changes and results

The usual detonation pattern of clearance x spacing at the Abóbora Mine is 3m x 7m or 4m x 8m, with a mining face 10 meters high and explosives loading ratio of 150 to 200 g/t. Since this design is implemented in the supergenic region, a significant unwanted volume of large blocks is produced and a new parameter has been proposed for this activity based on the geological model obtained using geophysical information as the input data. The change essentially involves positioning detonation drillholes in areas where large blocks of compact itabirite are located and reducing the number of drillholes in areas of friable itabirite.

The result has been a drop in the number of blocks. Before the change, 10% of the material was larger than 133 cm. After implementing the new method, 10% of the material is larger than 30 cm. There is also a minimum gain of 12% in productivity (tonnes per hour worked), as well as reduced losses produced by other transportation operations, which stood at 30%.
Loader L-1350 productivity

When the geological model refined with geophysical information is used to design the blasting operation, excavator productivity increases 12% compared to the model based solely on the original geological model. The refined model results in a blasting granulometry that is more homogeneous, as shown in the photo below.

In 2016, André Vieira and professor Jair Koppe presented a paper based on the research, also co-authored by Fernanda Pedrosa and José Carlos Ramos dos Santos (both engineers at Vale), at the World Mining Congress (WMC) in Rio de Janeiro.

Regarding the outcome of this partnership between the company and the university, André Vieira had this to say: “Our professional experience has identified an operational problem specific to the deposits at Vale, and therefore with no obvious or tried and tested solution. When we set about structuring a solution, collaboration with the university was fundamental. With its extensive background, the university provided support in establishing innovative technological concepts for our uniquely challenging situation. The result of this collaboration was the development of an academic/industrial solution considered to be a world class innovation. There is no doubt that this will motivate us to continue collaborating on research, leading to further post-graduate dissertations.”

Go to vale.com/MAIS-en and read the papers, master’s dissertations and other Fragcom-related content.

Glossary

Mineralogy: Study of the physical properties of the earth (heat, magnetism, radioactivity, gravity, electricity, elastic wave propagation, etc.) for investigating its inner structures, both in superficial layers containing mineral resources and in deeper layers.

Comminution: Fragmentation to break into smaller pieces.

Drillhole pattern: Geometric arrangement of drillholes for filling with explosives in a specific part of the solid rock.

Friable ores: Ores that fragment easily.

Weathering: Set of mechanical, chemical and biological processes resulting in the disintegration and decomposition of rock.

Metamorphic rock: Rock resulting from the transformation of the original rock by intense heat, pressure and fluid action.

Resistivity: Resistance to the flow of electrical current per unit volume of material.

Seismic refraction method: Method based on the principle of generating seismic waves using an energy source and recording the return signal by means of sensors.
In the Call for Proposals held jointly by Vale and the São Paulo State Research Support Foundation (Fapesp) in 2010, one of the selected projects was “Min_AO (short for Mining Asset Optimization): optimization of assets applied to open-pit mining operations,” developed by a team of researchers at the University of São Paulo (USP). Through this project, it has been possible to study the short-term planning process, including daily mining activity plans, at Sossego Mine in Pará, and to propose specific changes for this operation, based above all on process mapping methodologies.

Always focused on Sossego Mine and after analyzing each of the stages in the daily plan, the USP team was able to recommend improvements to permit a more integrated vision of the process and interdependence between the Areas involved in preparing the plan, such as Maintenance, Geology (quality control in mining sites) and Operations. The aim of this was to make planning more effective, besides emphasizing the need for automation of processes, team engagement, and integration of existing data in different systems used by Vale. Min_AO was also intended to enhance human resources management, including improvements to the interface between coordinators and supervisors of Areas, through meetings and workshops, which are set to intensify in future stages of the project.

Because of the success of this first project, completed in 2013, Vale’s South Atlantic Base Metals Operations Department and the Technology and Innovation Executive Management took the opportunity to continue the work, and commissioned the USP team to conduct a new study, called “Min_AO²: systemic management of mining planning and operations at mines of the future.” Started in 2014 and scheduled to end in 2019, this study seeks to enable Vale to develop a culture or “environment of systemic management” in its mining planning process, laying technical foundations capable of dealing with the challenges of the mines of the future. These
Challenges involve integration of information through systems; an integrated strategic vision, incorporated into the mining management process; and intensive communication and collaboration between supervisors and planners in real time. Min_AO² is also focused on the development of methodologies to permit the more intelligent use of data stored in different systems, using advanced simulation and artificial intelligence techniques.

Automating manual processes

Min_AO² is coordinated by professor Giorgio de Tomi, who has an undergraduate degree in mining engineering from USP, a master’s from Southern Illinois University, and a doctorate from Imperial College London. He is working on the project together with five other USP researchers and 10 Vale employees, who have different levels of interaction with the initiative.

“In this project, we have produced a development plan to automate procedures that used to be done manually and sometimes intuitively. We are using computational support to shape decisions, with a strong component aimed at culture: we need people to perceive the benefits that this will generate for the process and for them. So participation of employees in the project is fundamental,” says de Tomi.

The chart shows some improvements already obtained.

Engaged team

Sandro Freitas, a senior engineer in the South Atlantic Base Metals Operations Department, began his master’s at USP during Min_AO and he presented his dissertation on “Stochastic planning for the mines of the future” in 2015. Because of his familiarity with the topic, he was chosen from the very beginning of the project to be the contact person on behalf of Vale.

“One of my concerns is to associate the company’s needs with this research. In this process, the project does not need to be completed for us to obtain results. During the execution of Min_AO², we acquired a software program that featured artificial intelligence (based on neural networks) and also stochastic simulation and optimization (optimization in light of uncertainties) to analyze risks involving the availability of trucks. We also have a new mining sequencer for a procedure that used to be done manually. The idea is for us to become familiar with these tools and test them, and subsequently integrate these algorithms into the system that Vale is implementing this year,” says Freitas.

Allysson Sales, an engineer and technical specialist in the South Atlantic Base Metals Operations Department, is also working on this research. He has been doing his master’s at USP since 2016. He notes that Vale’s relationship with the university is longstanding. “We have managed to get around the issue of distance: many classes are given by videoconference and we have we have full support from the company to travel to São Paulo when necessary. USP’s team is great. We have grown professionally and brought knowledge to our operations. In my work, the idea is to reach an equation through which it is possible to associate the ore extraction load ratio with the SAG mill rate. As I apply a given load ratio to a specific rock characteristic, I will know how the mill rate will respond,” he explains.
Ana Carla Campelo, a Long-Term Planning engineer in the same department, began her master’s in 2016, focusing her study on integration between the dispatch system (responsible for transporting loads) and daily scheduling. “Before going to the Planning Area, I worked in the Dispatch Area, and during this time I realized that there was a lot to simplify when deciding what to produce from one day to the next, using information from our database. My work will be to define indicators and the way to treat them. I am very keen to do a doctorate afterward. It is important to emphasize that we also contribute a lot to the university, because they master the theory but they have little opportunity to see everyday operations, like we do,” she says. In October, Campelo attended ABM Week 2017, an annual event held by the Brazilian Metallurgy, Materials and Mining Association, at which she presented her paper, “Use of dispatch system data to estimate transportation productivity in short-term mining plan.”

“Min_AO was the first project in which we in the Technology and Innovation Executive Management proposed the participation of a Vale employee as a master’s student. This ended up becoming a best practice for the Operational Area involved in the project and it was decisive for the creation of Min_AO. This role of human resources development, coordinated with Operational Areas and the university, is fundamental to the process of knowledge transfer and the results of innovation projects,” says Edgar Sepúlveda, a Technological Development analyst at Vale.

**Toward smart mines**

Min_AO addresses a wide range of topics. The figure 1, prepared by the project team, shows the sequential phases of the project toward so-called “smart mines”.

The goal is to reach the integrated management stage and then proceed to the automation and online process control stage, before arriving at the envisaged comprehensive systemic management environment. On this journey, the project team was structured and the work plan was produced in 2015, and the following year the functional and technical requirements were identified and a specific solution to meet Sossego Mine’s demands was designed. In the next two years, training and capacity building for Sossego Mine’s team will be emphasized, to begin with the systemic management environment for mining planning and operations.

**Concept of systemic management**

At one of the workshops held in 2016 to disclose details of the project to Sossego Mine’s teams and discuss issues related to the scheduled stages with more than 40 Vale employees, professor Giorgio de Tomi explained the concept of systemic management. “The integration of different areas of knowledge is necessary to effectively interpret problems. The set of unitary actions involving each element generates an inflow, process and outflow chain, which enables the objective to be achieved by the system that contains the elements. Synergies should happen in such a way that the system as a whole has greater value than the sum of its separate elements,” he said.

At the same workshop, the interrelationships between the various processes involved in mining planning and operations were presented schematically (figure 3).
Technical and scientific production

Over the years, the project and its products, geared toward incorporating a systemic vision into mining, have been recognized both in academia and within Vale. In 2016, Vale engineer Sandro Freitas, after completing his master’s, was invited to teach a discipline in the specialization course on Mine Planning which was offered “in company” at the ITV Mining in Ouro Preto. At the time, many of the concepts worked on during the project, focused on mining planning, were conveyed to future Vale specialists who now work in various operations across Brazil.

In 2016, an article entitled “Simulation-based risk quantification: a reconciliation-based performance analysis” was published in the scientific journal Mining Technology (Transactions of the Institution of Mining and Metallurgy: Section A). The article explores a stochastic simulation-based methodology, applied to the Sossego Mine to analyze the risks associated with different grades of ore that feed the processing plant, quantifying the respective impacts on mining planning and defining mitigating steps for each scenario.

A lot of information has been incorporated, including the results of a study presented at the 2016 World Mining Congress in Rio de Janeiro, which looked at the productivity of each set of equipment, broken down by day of the week and shift. The paper, entitled “Challenges in the management of surface mining equipment” by Giorgio de Tomi, Tatiane Marin, Dennis
This is one example of an activity that is currently done manually, but will be automated in future, making things faster and more efficient. Today, looking at Sossego Mine’s experience, the process is much slower: a professional takes a photo of a mining site, goes to the office, saves the image on a drive and pastes it into a PowerPoint presentation, on top of which guidance to the actual mine operation is annotated.

The idea, like what has been happening in many operations around the world, is to integrate all the systems currently used into the ones that will be incorporated (figure 4). This will make planning and decision making faster and better quality, cutting out the need to fill in spreadsheets, for example, like the ones presently used to define daily schedules in the areas of drainage, drilling, operations, infrastructure and topography.

“In the near future, when I design a polygon in GEMS, which is our mining planning computer system, the history of activities stored in the daily planning database will be accessed and, based on past experience, I will have an automatic prediction of how long a given activity will take, in line with estimated area and volume. Likewise, the dispatch system’s database, which records the productivity of transportation equipment, will be an input for making predictions. Our focus in the project is to provide a receptive environment for these innovations, preparing people and guaranteeing greater effectiveness,” says Freitas.

“The database will be fed over the course of days, months and years with all this information, making it ever more robust. When we know that for situation X we should make decision Y, we will be able to learn from the database and use artificial intelligence to improve the performance of this decision-making tool,” adds professor de Tomi, anticipating things to come.
Integration and new culture

The main results so far are effective integration of information to support operational decision making in the mine, as well as team training to work in an automated environment. “It is also important to note that the implementation of this first version of the solution, developed by Vale, is paving the way for its future evolution to a decision-making environment featuring a probabilistic approach, using mathematical optimization and artificial intelligence models,” states de Tomi.

Tatiane Marin, a postdoctoral researcher at USP who tutors master’s students regarding Min_AO, has been following the project since Min_AO. She says that “the mines of the future will change the profile of jobs. We will need professionals with new competencies. That is why it is so important to prepare teams, show the scope for growth, emphasize the shift in culture, and work on the idea of innovation. We are doing these activities this year, while accompanying the implementation of the tool developed by Vale. In 2018, we will evaluate the results.”

Visit vale.com/MAIS-en to read articles, master’s dissertations and other content related to Min_AO and Min_AO².

Get involved

Is systemic management a concept that is part of your activities? Are the operating systems in the Area where you work integrated? Are your databases fed with information that can help you to make decisions? Talk to Vale’s team by emailing MAIS@vale.com and find out more about the Min_AO² project and all the possibilities it is generating. The project will be completed in 2019.

Glossary

Stochastic simulation: Applied simulation technique to represent the behavior of complex systems using their randomness to generate alternative and equally probable scenarios concerning possible outcomes of these systems.

Mining sequencing: Mining planning cycle activity to determine the order of ore extraction through the lifespan of a mine, taking into account a deposit’s operational, financial, environmental and geological restrictions.

Dispatch system: Management and control system for all equipment involved in unitary mining operations, encompassing mining site preparation and access, drilling and blasting, production of ore and waste rock, operational support, and mine infrastructure.

Artificial intelligence: Area of computer science knowledge that consists of the representation of human intelligence using computers. Applied particularly to complex systems whose outcomes are hard to interpret and analyze.

Deterministic approach: Modeling method in which the behavior of a system is pre-established and the results depend on the input data of the model.

Stochastic approach: Modeling method in which the results do not only depend on input data, but also other factors and variables, which are specified through probabilistic functions.

Mathematical optimization models: Type of mathematical model aimed at optimizing a target function – either maximizing or minimizing it – without violating the restrictions of the represented system.

ROM: Run of mine, meaning all the ore extracted from a mine in a given period, to be sent to a processing plant or temporary storage piles.
Biotechnology speeds up environmental solutions in the field

Used on railroads to increase the durability of timber sleepers, mineral creosote is a complex chemical compound, usually consisting of 85% polycyclic aromatic hydrocarbons (PAH), 10% phenols and 5% heterocyclic compounds of nitrogen, sulfur and oxygen.

In the past, when the extensive knowledge we have today about the consequences of using creosote was not available and there was no legislation on the subject, Vale used creosote in the Sleeper Treatment Unit (UTD) in João Neiva, state of Espírito Santo. Today, the company imports pre-treated sleepers, preventing environmental impacts, and runs environmental checks and implements remediation in the former creosote treatment area.

In 2015, to supplement the work carried out by the company in João Neiva, a project was inaugurated, titled “Research and technologies for the bioremediation of creosote-contaminated Vale property”, and conducted by a team of researchers from the Federal University of Minas Gerais (UFMG), with the support of Vale’s Environment Executive Management, and Technology and Innovation Executive Management.

Creosote is mostly composed of PAHs listed as organic pollutants by United States Environment Protection Agency (EPA) and assigned high priority in monitoring programs. The more aromatic rings a compound contains, the greater its mutagenic and/or carcinogenic potential and the more difficult it is to degrade.
Application in a controlled area

Guilherme Alves, environmental analyst in the Environment Executive Management that provides project support, assures that “contamination is restricted to a controlled area inaccessible to people and therefore presenting no risk to the local community. We presented the case of João Neiva to the Brazilian Institute for the Environment and Renewable Natural Resources (Ibama) and other environmental agencies in order to develop the remediation project. During the process, we realized that this was an opportunity to work with biotechnology to optimize remediation work on the soil and aquifers that was being carried out in the locality.”

The research is headed by professor Vera Lúcia dos Santos of the Microbiology Department at the Federal University of Minas Gerais (UFMG). She graduated in Agronomics from the Federal University of Viçosa (UFV), where she also studied for a master’s degree in Agricultural Microbiology and doctorate in Genetics and Breeding. She was a post-doctoral fellow in Environmental Microbiology and Environmental Biotechnology, also at UFMG.

Vera Lúcia had already conducted a study in partnership with Vale following a Call for Proposals published by the company in conjunction with the Minas Gerais Research Support Foundation (Fapemig) in 2010. This initial project, which resulted in a patent for a method of removing metals from solutions and the use of microorganisms for degrading polycyclic aromatic hydrocarbons, was the reason Vale invited the UFMG team of nine researchers to take part.

A challenging substance

“Creosote is formed by extremely recalcitrant compounds, difficult to degrade for living organisms, and taking a long time to degrade under normal conditions. Vale had already contracted a company to remediate the area using physical and chemical means and pioneering equipment to cut and adequately dispose of cylinders of contaminated soil, pump away the creosote and map the level of local contamination. Bioremediation was intended as a supplementary approach, a technique based on the use of biological agents or their products, such as enzymes to remove toxic components, whether by adsorption, deactivation or mineralization,” the professor explained.

Microorganisms are fairly widely used for this job because they have very diverse metabolisms. For instance, bacteria manage to produce energy by oxidizing organic and inorganic compounds, including those that are found in nature, such as cellulose, starch and lipids, as well as non-natural molecules, the so-called xenobiotics. Microorganisms are also versatile from a physiological viewpoint, since they can grow in a basic, neutral or acid pH environment, at high and low temperatures, in the presence or absence of oxygen, and under a variety of other conditions.

Autochthonous microbiota

To conduct a study with this profile, it is important first to assess whether existing autochthonous microbiota are capable of degrading the compounds. If so, an attempt is made to stimulate the growth of the microorganisms by adding oxygen and nutrients such as phosphorus and nitrogen. Since the aromatic molecules in the compounds are not soluble in water and the microorganisms need the presence of water to degrade them, the process also involves adding synthetic or biological surfactants, substances that allow the compounds to mix with water.

If there are no suitable microorganisms in the ground for degrading the contaminants, inoculants are added containing a considerable volume of bacteria that can do this. Ibama regulates and is responsible for authorizing the use of inoculants, which are widely employed for remediating eutrophic lakes and contaminated soils. “It is very rare for the contaminated soils not to contain the microorganisms we need, since they are fairly ubiquitous in the environment. In the case of Vale, if it is necessary, isolated microorganisms will be inoculated in the area, validated in the laboratory and in the field, and notified to Ibama. Once approved, these products can be used in other areas,” said Vera Lúcia.
concentrations of the majority of the compounds of interest; two wells with medium concentrations; and three uncontaminated wells.

**DNA extraction and determination of bacterial species richness**

Metagenomic DNA was extracted from the samples and subjected to a polymer chain reaction (PCR) to amplify the V3 and V4 regions of the gene in subunit 16S of the bacterial rRNA, followed by sequencing on the Illumina platform. This method allows to identify cultured and non-cultured bacteria present in the study area. Based on the number of sequences obtained and using bioinformatics software, the abundance of bacteria was predicted for each phylum, class, family and genus. Analysis led to the conclusion that the presence of the contaminants altered the profile of the bacterial community in the locality, enriching various groups of bacteria that degrade PAHs, predominantly in samples with high levels of contaminants.

In one stage of the study, the density of total heterotrophic bacteria (THB) and bacteria that degrade PAHs, phenols and creosote was determined in microplates from 96 wells using the most likely number (MLN) method. To determine THB the bacteria were cultured on R2A medium. Degrading bacteria were quantified using Bushnell-Haas medium and adding PAHs (naphthalene, anthracene), phenol and creosote. In general, the density of THB dropped in direct proportion to the level of sample contamination, whereas the density of bacteria that degrade naphthalene, anthracene and creosote increased.

The density of bacteria and Arqueas (prokaryotes similar to bacteria but structurally different) in the samples was also measured using the qPCR method, and the result visualized in real time during amplification of the sequence of interest. After analysis, it was concluded that the density of bacteria in the most contaminated samples from the aquifer was lower than in samples with lower levels of contamination, whereas the sediment samples from the lake showed no variation in density as a function of the level of contamination. Furthermore, bacteria were predominant compared to Arqueas in all samples.

Based on this reasoning, microbial diversity is assessed, identifying species and density of microorganisms in the area in order to answer the following questions: Which microorganisms are where and in what quantity? What is the catabolic potential of this autochthonous microbiota?

**Stages in the study**

Initially sediment samples were collected at various points in a lake within the affected area and solid and liquid samples collected from aquifer monitoring wells set up by the company responsible for remediation. Based on the well selection criterion - mean concentration of various volatile (VOC) and semi-volatile (SVOC) organic compounds - three groups of wells were defined as a function of the concentration of 31 contaminants: three wells with high concentrations of the majority of the compounds of interest; two wells with medium concentrations; and three uncontaminated wells.

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**Os Wells and sediment samples were clustered according to the concentrations of the contaminants found in each sample.**

**Wells with higher levels of contamination by the compounds of interest:**
- Acenaphthene (higher than 80.0 μg/L), Anthracene (higher than 7.5 μg/L), Dibenzofuran (>111.0 μg/L), Fluorene (higher than 71.0 μg/L), Naphthalene (higher than 1500 μg/L).

**Wells with intermediate/low contamination by the compounds of interest:**
- Acenaphthalene (0 to 80 μg/L), Anthracene (0 to 12.5 μg/L), Dibenzofuran (0.58 to 74.0 μg/L), Fluorene (0 to 95.5 μg/L), Naphthalene (0 to 2500 μg/L).

**Wells uncontaminated by the compounds of interest:**
- Naphthalene (0 to 2500 μg/L).

Aquifer and sediment samples can be organized in clusters which generally indicate the correlation with levels of contaminants, based on multivariate principal component analysis (PCA) using R software.
Isolation, enrichment and profiles of communities

In the laboratory, degrading bacteria were isolated from the samples, enriched with phenol and creosote to provide sources of carbon, and stirred for seven days at 28º C. After this stage, the profiles of the bacterial communities present in the sediments and water were determined by PCR-DGGE (denaturing gradient gel electrophoresis) to differentiate the products of PCR (amplified DNA segments) according to their nucleotide sequences.

Analysis confirmed that the creosote contamination had altered the local microbiota. In wells with the highest concentrations of PAHs, the microbial communities differed from those in wells with little or no contamination.

Isolates bank

Based on the enrichment method, it was accumulated a bank of 212 bacteria with the potential to degrade PAHs, phenols and creosote and/or producers of tensioactive compounds. The bacteria belonged to 27 genera: Achromobacter, Brevundimonas, Leucobacter, Paenibacillus, Bacillus, Sphingobacterium, Alcaligenes, Burkholderia, Citrobacter, Comamonas, Delfia, Enterobacter, Enterococcus, Kosakonia, Nubsella, Pseudochrobactrum, Pseudomonas, Psychrobacter, Rhizobium, Rhodococcus, Senia, Stenotrophomonas, Acidovorax, Pandorea, Diaphorobacter e Ralstonia.

Conclusões

Professor Vera Lúcia affirms that, once all these phases had been completed, “we discovered genera of bacteria capable of degrading almost all the compounds in creosote and others capable of degrading specific PAHs. Our studies will now focus on the best performers. In the final part of the experiments, conducted with a respirometer acquired using project funding, we inoculated microorganisms into the samples sent by Vale and added nitrogen and phosphorus to assess how the bacteria would behave in a matrix close to the real conditions in João Neiva. This allowed us to select bacteria with the highest contaminant degradation rate. Then the process could be applied in the contaminated location. Another positive result of this study is that...”

The isolates that produced the best results for degrading the 12 compounds evaluated and with the most potential for use in bioremediation in environments contaminated with PAHs are circled in red.
we will be able to create protocols for bioaugmentation and biostimulation in the laboratory, in order to cut costs and speed up the remediation process.”

Environmental analyst Guilherme Alves said that a pilot project was under way in collaboration with the decontamination company to take the study results and apply them in the field. Marcos Borba, environmental liabilities manager in Vale’s Environmental Executive Management, had the following to say: “The partnership with the researchers has been very interesting. We set up a workshop involving Vale and UFMG and meetings to discuss technical issues were held every three months to exchange experiences and build the team’s technical capacity. The university went into the field, and we went to the university.”

“We do not have disciplines to prepare people for corporate life. This kind of research makes this easier and helps train our students, as well as being an opportunity to take on one of the challenges we face: transforming basic research into useful products and processes that can be applied in the field. From a biotechnology viewpoint, implementing this project in partnership with a company the size of Vale is important, because corporations rarely follow through and conclude bioremediation projects with systematized monitoring. Pioneering work, whatever form it may take, is always gratifying,” said Vera Lúcia.

“Interaction among the Technology and Innovation Executive Management, researchers and the Environment Area has taken us from the initial Call for Proposals to a second, more practical, project. Now, with the laboratory equipment already procured, this shared experience could take us to other locations, such as the north of Brazil, in a third phase. This is the outcome of innovation management,” said Edgar Sepúlveda, Technological Development analyst responsible for interfacing project participants.

Do you know of any other localities at which biotechnology could be useful for remediating environmental damage?
Would you like information on the procedure to follow?
Would you like to talk to Vale’s professionals responsible for overseeing the UFMG study?
The research project is scheduled for completion in 2018 and is worth sharing. Get in touch with the project team by emailing MAIS@vale.com.

“Adsorption: Process by which atoms, molecules or ions adhere to a surface by means of chemical or physical interactions.”

“Mineralization: Process in which an organic substance is converted into an inorganic substance.”

“Volatile compounds: Carbon-containing compounds that boil at between 50 and 260°C.”

“Heterotrophic bacteria: Bacteria incapable of producing their own food and depending on the oxidation of existing organic matter to produce the energy they need.”

“Polymerase: Enzyme that synthesizes long chains or polymers of nucleic acids.”

“Eletrophoresis: Process whereby electrically charged particles in solution migrate to electrodes.”

“Emulsifier: Molecule that has a polarized group (attracting water) and a non-polarized group (attracting organic compounds) allowing the interaction of non-miscible phases, such as oil and water.”

“NMDS: Non-metric multidimensional scaling. A technique whereby a number of attempts are made until a solution to the problem is found.”

“Metagenomic: Relating to metagenomes, genetic material recovered directly from environmental samples.”

“Eutrophic: Relating to an aquatic environment containing high levels of organic and inorganic nutrients, generally as a result of human activity.”
Comments, suggestions or questions?

Email MAIS@vale.com