Considerations on Research Efficiency and Knowledge Transfer in Environmentally-Based Research Groups

by

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Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in Mechanical Engineering
at the
Massachusetts Institute of Technology

June 2008

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ABSTRACT

A literature survey of how research groups and communities go about sharing ideas and transfer knowledge was performed. Previous studies were explored and used to ascertain how research groups spend their time. Collaborative efforts were also taken into consideration, and a correlation is made between research efficiency and collaboration.

Based on the literature, the author found several studies supporting a positive relationship between collaboration and research efficiency. Furthermore, it was also suggested that, although quantifying performance and efficiency is challenging, research efficiency can be measured through a few quantifiable and dynamic metrics. In order to accurately and definitively test how efficiently research groups conduct research and knowledge transfer is made, a larger and more complete study is needed.

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Title: Professor of Mechanical Engineering and Engineering Systems

Contents

1. Introduction

1.1 Motivation

As the ability to reach one another globally and to easily communicate synchronously and asynchronously, opportunities for collaborative research and knowledge transfer has increased dramatically[1]. Researchers in different parts of the world can communicate and collaborate on the same project if need be, drastically improving the rate at which research is conducted[1]. This increased ability to transfer knowledge amongst researchers has developed its own set of drawbacks, however; the flood of information makes it increasingly difficult to determine what research other groups have conducted recently or are conducting currently.

Research done in parallel is not necessarily ideal – it is both unproductive and inefficient. Though parallel research can be confirmatory, and competition amongst groups can lead to higher productivity, it does not optimize utilization of available resources. Financial resources are often not distributed economically as a result. Furthermore, inefficiencies and unproductiveness in research inhibits 'bad' performers from learning from 'good' performers[2]. Determining how a particular performer performs is a problem in and of itself since how quickly one produces results is not a concrete indicator of how efficiently one works[3]. Of particular interest is where research groups are spending their time. With the wealth of knowledge available, it can become tedious to look up previous or current research projects that might be similar to what is being proposed. The focal point of this thesis is to determine where research groups are spending their time and to devise a method or methods to make their work more efficient.

1.2 Overview

This thesis surveys research conducted to determine how large research groups go about sharing ideas and how knowledge transfer within these groups is made. The goal is to consolidate these findings for existing knowledge-sharing projects, particularly those with an emphasis on or a specialty in environmental-based research.

Section 2 delves into background information and related work. Research groups are discussed, as well as the challenges that are associated with attempting to develop a set rubric for determining where and how research groups spend their time. Additionally, a few current research networking sites are looked into in some detail, since the goal is to incorporate findings into these sites.

Section 3 discusses the findings of this thesis and details how to best incorporate said findings into the aforementioned internet sites.

Finally, section 4 concludes this thesis with a recap and closing remarks. Possible directions for future study are briefly discussed, as well.

2. Background

2.1 Related Work

There have been a myriad of studies conducted where committees or groups attempt to assess how efficiently research is conducted on all scales and in many fields. These range from small groups within a university to much larger organizations such as the United States Environmental Protection Agency[13]. In this section, a review of these studies is given and their methods and results are discussed in detail. Key points and relevant information and results as they pertain to how research groups spend their time will be pointed out. The purpose of this review is to determine a correlation between research efficiency and time and make connections to environmentally-based research groups.

Additionally, the challenges associated with assessing research efficiency in conjunction with how information is obtained and distributed will be discussed. Lastly, a synopsis of a couple research networking sites will be discussed.

2.1.1 Research Efficiency

"On Research Efficiency" (Cherchyle & Vanden Abeele, 2002) is a study that was conducted at Dutch universities between 1996 and 2000, administered by the Association of Dutch Universities (VSNU), specifically in the Economics and Business Management departments. The group made an attempt to quantify the universities' research efficiencies by proposing a set of input and output parameters to measure performance.

Their primary focus was on micro-units of research – research programs – where a group of researchers come together and utilize the same resources in order to study a particular topic. They are of the opinion that these 'micro-units' of research more accurately portray the efficiencies and deficiencies of academic research; studying 'micro-units' provides better and more detailed insight as to how units of different specialties differ within a department at a given university or within a particular specialty across several universities.

The authors go about measuring efficiencies by attempting to explain significant differences in performance. Consideration is given to variations in efficiencies over the period of the study, as well as in given specialties. They then attempt to use regression analysis to discern a relationship between observed efficiency and the size of the research program and the extent of their financial support.

Due to the lack of concrete structure or that errors-in-data are not accounted for in their model, research *inefficiencies* were hard to account for, particularly after considering that the methods employed specifically attempts to explain discrepancies. Knowing this, the authors advise that the results should be used to screen research programs and direct attention towards any discrepancies; the results should not, however, permit one to draw conclusions on a particular research group regarding performance. More in-depth analysis or investigation is required in order to determine the performance of any acutely problematic program.

The study concludes favorably with the authors' prediction. Upon receipt of the data, the Dutch universities submitted their own assessment of the research programs involved. They were rated on a scale of '1' to '5' (where '1' is poor and '5' is excellent) on 4 criteria: quality, productivity, relevance, and long-term viability. The 'efficiency measures' of the study correlated very strongly with all but one of the criteria given by the Dutch universities: long-term viability. This was expected, however, considering that the method does not necessarily account for inefficiencies.

When comparing the efficiency of groups of research programs, the group found there to be differences from one group to another; this was expected, considering that different specialties require different sets of resources. The most that these data can suggest is that some groups can learn from the organizational structure of others. Furthermore, they conclude that a generally poorly performing university is not necessarily operating inefficiently in any given specialty.

In terms of research groups themselves, it was found that the amount of external funding a group receives correlates with how efficient that group performs; i.e.., that group was particularly productive on any given year. Size, however, did not have an effect on performance.

2.1.2 Collaboration

It is assumed that collaboration between research groups in the same field or specialty will yield better results more quickly; resulting in higher research efficiencies and productiveness. Efficiency and productivity is assumed to be correlated to time spent for an outcome. "What is Research Collaboration?" (J.S. Katz & B.R. Martin, 1995) examines the relationship between collaboration and productivity on several scale levels[4]: Individual, Group, Department, Institution, Sector and Nation[i].

The authors begin by examining collaboration among researchers by exploring previous research and dividing that research into four subcategories: measuring collaboration, possibly through the analysis of multiple-author papers; the factors involved in forming research collaborations; the sources of collaboration; and the effects collaboration has on productivity and its impact on joint-research.

Previously, multiple co-authored publications were used to measure collaborative activity – an increase in the prevalence of co-authored publications suggested an increase in collaborative effort[5]. However, one should not so quick to assume that co-authorship

[i] For a table listing the different levels of collaborations and the distinctions between *inter*- and *intra*-forms, please refer to Table 1 in Appendix A

is the sole indicator of collaborative effort[6]. The factors that go into determining how much effort went into collaboration differ greatly from group to group and project to project. The amount of time invested by both collaborators, for example, maybe a solid indicator, whereas an exchange of ideas in the midst of conversation may have greater impact on the project overall. Despite that co-authorship is not a concrete method of determining collaboration in research, there are several other studies that support the idea that co-authored publications have been increasing[ii]. Despite the general consensus that multiple-authorship is an indicator of collaboration, there have a few instances where authors' names are added for honorary[7] or social[8] reasons. Although analyzing collaboration among researchers using co-authored publications is flawed, it still presents an enticing argument for analysis: co-authored publications are, by definition, published works, so they are verifiable; everyone has access to the same data set (with a few exceptions such as proprietary, patented, or confidential works); this data set is insurmountably large, making studies utilizing this data set more noteworthy than other studies utilizing different samples; and it is an un-intrusive method of determining collaboration without affecting the collaboration process.

One can speculate as to why researchers collaborate - and those speculations may amount to many reasons – but there are only a few specific factors that contribute to collaborative efforts. As stated before, there are many variants to collaboration, and there are no guidelines as to what makes a certain researcher, peer, expert, colleague, etc., a collaborator[9]. In prior literature it has been has proposed that there are many reasons that might contribute to the increase in co-authored publications[iii]. It appears that collaboration might be related to the nature of the work[7]. Preliminary observations indicate that theoretical publications often tend to have fewer co-authors than their experimental counter-parts. Further investigation has led to the belief that experimental work yields more collaborators because of the sheer nature of the work[10]. Additionally, larger experiments or experiments requiring large and/or complex equipment tend to see collaboration more-so than smaller, simpler experiments[11]. One of the referenced

[ii] For a list of select studies on co-authorship trends in multiple subject areas, please refer to Appendix B

authors[7] argues that experimental works typically tend to be interdisciplinary; that is, experimental works require the skills and/or resources of a wider range of disciplines than any single individual might possess.

Collaboration maybe driven by many factors, as stated before. The source of these factors is a topic of debate amongst researchers. Economic factors[10] – the need for money or the ease with which money is distributed to projects that have multiple researchers – is a major factor, as is mutual intellectual and social influences[8]. One factor that drives collaboration and seems to be generally accepted as truth is proximity. Proximity encourages collaboration amongst researchers because it promotes more informal communication[7]. In fact, studies have shown that collaboration on publications drops off exponentially as the distance between institutional partners increases[12].

When researchers collaborate on research, it if often assumed that the researchers together are more efficient than one researcher on his or her own. Some researchers, however, are more prolific than others in terms of the number of publications published per group. The author's research has led him to believe that a positive relationship exists between productivity and level of collaboration[iv]. Simply put, the most prolific authors tend to collaborate most frequently with others. Additionally, papers with multiple authors have a higher propensity of acceptance by leading journals for publication[9], reasons being that more trust can be placed in the work: multiple authors, particularly in the same or similar field, allow for greater display of technical competence, as well as the opportunity for checking the overall work.

There are benefits to collaborating. Learning all the skills/gaining all the experience necessary to perform most of today's research is a time-consuming task, particularly since much of today's research is interdisciplinary or ground-breaking. Collaboration allows for the sharing of knowledge. Additionally, collaboration allows

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[iii] For the list of factors presented in *What is Research Collaboration?* and associated references, please refer to Appendix C

[iv] For a list of literature that supporting this position, please refer to Appendix D

for knowledge transfer; rather than re-train or update an individual, knowledge can be transferred within a group or to other groups before any publication comes about.

2.1.3 Research Efficiency in the U.S. Environmental Protection Agency

Research is conducted at the national level by many federal institutions. In this respect, the United States Government is the governing body over the many institutions that conduct research and development (R&D). Funding, in this case, is provided by the taxpayers. In order to put the taxpayers' money to the best use possible, Congress passed the Government Performance and Results Act in 1993. Thereafter, the Office of Management and Budget (OMB) designed the Program Assessment Rating Tool – or PART – in 2002 with the intention of improving research efficiency.

It has already been established that assessing the efficiency of research groups is a difficult task. Many factors play a role in how research is conducted within a group, between groups, and on to increasingly larger scales. After having difficulty complying with PART requirements, the Environmental Protection Agency (EPA) requested help from the National Academies in 2006 to develop better ways of assessing and measuring efficiency to comply with PART[13]. A committee was appointed in order to tackle the task; they devised a rubric that required the surveying of the EPA and other federally funded R&D programs, the sufficiency of those measurements, the principles needed to guide development, and the needed efficiency measures to be used[v]. The EPA's logic model for evaluating its R&D programs can be found in Appendix F.

Many of the difficulties the EPA experienced in trying to comply with PART requirements stem from confusion over what "efficiency" means. Through review of OMB PART guidance as well as preliminary efficiency measurements used by the EPA (and other federally funded agencies) the committee came to the conclusion that there are

[v] The question used for the evaluation, as well as definitions for terminology used by the National Academy of Sciences and other pertinent information can be found in Appendix E

two kinds of efficiency – *investment efficiency* and *process efficiency* – and both are essential to the implementation and assessment of R&D programs. *Investment Efficiency* is primarily managerial in nature; it involves the need to "identify the most promising lines of research for achieving the desired outcomes[12]." Investment efficiency is determined by assessing any given program's research activities throughout its course (planning to execution). *Process Efficiency* concerns itself with the actual inputs and outputs of the research. Evaluating process efficiency deals with how well processes within a given research subject are conducted. Publications, grants, quantitative laboratory analysis are all monitored using metric such as dollars, hours and so on.

The issue of having a "sufficient" measure of efficiency is one that has proved troublesome. None of the metrics proposed by federally funded agencies were enough to assess investment efficiency and that many of the appropriate metrics were not sufficient to evaluate process efficiency. Looking at other agencies for metrics does not help the EPA, since many similar metrics have been proposed for assessing efficiency and several have been rejected.

The committee also determined that of the two kinds of outcomes associated with efficiency, intermediate outcomes and ultimate outcomes, only intermediate outcomes prove of any use in evaluating research efficiency. The basis behind this is that ultimate outcomes are not predictable, occur outside of the research's time period, and are dependent on factors outside of the scope or control of the research.

2.2 Challenges

There are many challenges associated with attempting to analyze how research groups conduct their research, how they spend their time (productivity and efficiency), and how they transfer knowledge. Previous studies have made attempts to quantify the efficiency of research. Different methods have been used and different resources utilized, however the many factors involved with conducting research – number of people involved, subject area, location, funding, scope of the research, resources available, productivity, amount of time required to conduct the actual research, etc – make it difficult to have a set of concrete guidelines for determining how efficiently research groups perform.

Metrics have been proposed by different studies to determine research efficiencies. Again, it must be noted that these metrics can and will differ from group to group and from study to study; studies have agreed, however, on certain factors contributing to research efficiencies, however some factors are contested. Determining the reasons why some factors are not agreed on is also challenging; though data sets may be large and the goal is the same, the methodology differs, as does the sample set. A study determining research efficiencies in economics and business management departments will differ from efficiencies in science-based departments. Furthermore, collaborative efforts between or within groups will differ greatly due to differences in motivation to collaborate; motivational factors behind collaborative efforts are difficult track and quantify, and their effect on research is challenging to quantify.

2.3 PEMS Web & Related Sites

PEMS Web, Public Environmental Modeling and Simulation Web, is an internet project that allows public access to a network of computer-based environmental research models and simulations. PEMS Web is a site where one can go and run models and simulations that are environmentally focused in order to gain a better understanding of how they are contributing or detracting from the environment. The website gives users the ability to create their own models or simulations and integrate them with current models. PEMS Web also maintains a forum where individuals can engage in environmentally-based discussions.

PEMS Web is a pilot program – that is, it is a fairly new project and is in the process of development. Associated through the CADlab (Computer-Aided Design lab) under Environmentally-Conscious Design at the Massachusetts Institute of Technology, PEMS Web has the potential to become a hub of idea-sharing and knowledge transfer.

Blackwell Synergy is another site that aligns itself with online research. More of a database than anything else, Blackwell Synergy has a wealth of information in the form of archived magazines. Blackwell does have a fairly extensive database which allows for readily available and easily accessible information.

These sites allow materials and information to be collected and located in one central location, allowing for time and effort to be minimized when conducting research.

3. Findings & Discussion

Determining the efficiency of research groups is a difficult task. Previous literature states this, and even then, past methods of determining metrics to measure and assess research efficiency and knowledge transfer have proved difficult. Still, however, studies and research in the topic of research efficiency have proven to yield promising results.

It is best to look at research groups at a smaller scale than, say, the United States Government. Smaller research groups are easier to manage and knowledge transfer amongst researchers tends to work well. Before delving further into how findings will be handled, some definitions need to be clarified. For the purpose of these findings and subsequent discussion and conclusion, *efficiency* means how productive a group is and how well a group spends their time. *Productivity* is the amount of quality material that is produced, where quality will mean recorded and published. *Knowledge transfer* is, for the purpose of this thesis, literally the transfer of knowledge from one group or individual to another group or individual for research purposes. *Inputs*, *outputs* and *outcomes* will be defined as previously defined by the National Academies[vi].

It is possible to use certain metrics to determine efficiencies, but more than just any one given metric is needed. The number of publications a given research group has is a good metric to determine productivity in the sense that that particular group is prolific and produces publishable work fairly often; it says nothing, however, about the group as a whole. In determining the required metrics to assess research efficiency, one must also take into account the effect any form of collaboration within or involving other groups.

One should also take into account that it is possible to have parallel research projects; information sharing and knowledge transfer is paramount to being efficient in

[vi] See Appendix E.

situations such as this. Two research groups working in parallel on the same or similar research is a poor use of resources; not only is funding for either group spread throughout the two, but it is a poor utilization of materials. Furthermore, determining efficiencies and weaknesses in a group is more manageable when these groups are separated into micro-units. From here, focus can move onto larger groups, analyzing inter-group collaboration first, and then collaboration with other groups.

Additionally, only certain outcomes are valid when determining research efficiency and knowledge transfer. Long-term results that are not pertinent to the research do not indicate how efficient a group has been, nor is it any indication of how knowledge is transferred from the group to other sources.

It is of my opinion that it is in research groups' best interest to collaborate on research and consolidate data. The difficulties associated with assessing what constitutes as collaboration (and, in fact, it can very well differ greatly from group to group and subject area to subject area) make it difficult to determine if parallel research is being performed by different groups. Also, how information is passed from one group to another becomes either time-consuming, costly or both. Archives are available and accessible today to anyone with a connection to the internet; searching through those archives, however, tends to be tedious and time-consuming.

What is needed in order to better serve research groups is a shared database where information can be freely requested and exchanged; models and simulations can be generated and tested; and forums can be held where anyone can inquire on particular research. Works-in-Progress can be described by any research group, keeping other research groups updated so as to better prepare planning and execution of the next research project[vii].

[vii] Please refer to Mika Tomzcak's graduate thesis for an example of work-in progress. Tomzcak is a graduate student at the Massachusetts Institute of Technology in the Department of Mechanical Engineering.

It is interesting to note that one of the main factors cited that lead to collaboration among researchers is proximity. With the advent of the internet and the ease with which communication has become, the 'traditional' definition of proximity becomes skewed since his or her relative proximity to other researchers can be as close as a phone-call or mouse-click. Having a central database (as described above) can skew this line further, provided the capability to share research privately with his or her colleagues almost instantaneously is there.

The proposed shared database has its own implications. First and foremost, it has been assessed that proximity plays a large role in collaboration amongst researchers. Consequently, those collaborations not only bring about more publications, but it also maximizes funding and resources – it has been shown that more collaborators correlate to increased project funding and greater utilization of available resources. Additionally, increased collaboration is typically an indicator of projects that require more resources, more funding and are interdisciplinary. If a project is interdisciplinary, then researchers from more than one subject area are involved, increasing the chances of knowledge transfer among the group's members.

One topic of debate that is related to the issue of increased collaboration is the relationship between group size and research efficiency. Whereas the authors of "On Research Efficiency" did not find nor did they believe that a correlation exists between group size and efficiency, the authors of "What is Research Collaboration?" discovered the contrary. It is my opinion that J.S. Katz & D.R. Martin are correct in stating that collaboration is good and stimulates research.

4. Conclusion & Possible Further Study

Analyzing and determining research efficiencies and the way in which knowledge is transferred is an extremely daunting and difficult task. Previous literature has proven that analyzing research efficiency is challenging, particularly since valid quantifiable metrics for identifying efficiencies are scarce. Additionally, identifying universal metrics – that is, metrics that can be used universally for all areas of research – is even more difficult considering that research differs greatly between subject areas. Moreover, the very nature of scientific research disallows itself to accurately determine what qualifies as productive or efficient research; negative results which would superficially be measured as "inefficient" can have great value for the research.

Though analyzing how research groups spend their time and how efficiently they conduct research is challenging, it is not impossible. Metrics used for analysis for scientific research groups can be as benign and quantifiable as the number of people working on a given project or the number of publications a given researcher or groups; they can also be more qualitative, which unfortunately leaves certain metrics up for interpretation. Simple analysis of a limited sample set is not ideal; preferably, a large sample set taken over a fairly long period of time.

Efficiency analysis of research groups is paramount in determining not only how to best manage a group as well as where and how to allocate research funds and resources. Collaboration between groups bares analysis as well, considering that communication between groups is almost effortless. The problems associated with collaborating between and within groups are not necessarily due to lack of communication. Instead, the difficulty associated with searching (and, conversely, archiving) research, data and publications prove problematic for determining if similar research is presently being conducted.

A proposed solution is to incorporate metrics used in other studies to analyze research efficiency into a medium that is both easily accessible and readily available to research groups. Also, a central database of archived materials that are categorized by the usual categories (year, volume, journal, etc.) as well as non-conventional categories (keywords, data sets, research period, etc) could be beneficial to research groups. A forum should be provided, as well as profile pages for research groups in order to promote collaboration between groups. A perfect vehicle to implement these ideas would be PEMS Web.

PEMS Web is a developing environmentally-based research website, geared towards networking amongst researchers. The site also has models and simulations and users have the capability to create and share their own models and simulations. Users, upon registering, can create a brief blurb in their profile, describing what it is that they do and who or what organization they are affiliated through. Implementing the aforementioned ideas into PEMS Web would require some effort, but should be minimal; it is my opinion that PEMS Web's current platform and organization allow for the integration of research groups. The site will need to be able heavy traffic if it is to succeed, as well as maintain a high profile amongst research communities to attract research groups.

This research and analysis can be expanded by having a set of clear, dynamic metrics to measure research efficiency and determine groups' collaborative efforts. Research would preferably span several years in order to maximize sample sets and optimize data by exploring research efficiency and collaborative efforts on multiple scales. Both inter- and intra- group dynamics should be taken note of, and research between groups that are not in close proximity to one another should be of particular interest to determine if proximity is as much, if at all, an issue as it was before the advent of the internet and electronic mail. Additionally, knowledge transfer between and within groups should be analyzed to determine if changes are necessary to how information is presently distributed.

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Appendix A

Collaboration Levels & Distinctions

Table 1: Levels of Collaboration and Distinctions between *Intra-* and *Inter-* Collaboration*

	Intra	Inter
Individual	-	Between individuals
Group	Between individuals in the same research group	Between groups (e.g. in the same department)
Department	Between individuals or groups in the same department	Between departments (in the same institution)
Institution	Between individuals or departments in the same institution	Between institutions
Sector	Between institutions in the same sector	Between institutions in different sectors
Nation	Between institutions in the same country	Between institutions in different countries

*Taken from J.S. Katz & D.R. Martin (1997): "What is Research Collaboration?", *Research Policy*, Elsevier, vol. 26, 1-18.

Appendix B

List of Select Studies on Co-authorship Trends in Multiple Subject Areas

C. Balog (1979-1980): "Multiple Authorship and Author Collaboration in Agricultural Research Publications", *Journal of Research Communication Studies*, vol. 2, 159-169.

D. deB. Beaver & R. Rosen (1978): "Studies in Scientific Collaboration: Part I – The Professional Origins of Scientific Co-authorship", *Scientometrics*, vol. 1, 65-84.

D. deB. Beaver & R. Rosen (1979a): "Studies in Scientific Collaboration: Part II - Scientific Co-authorship, Research Productivity and Visibility in the French Scientific Elite, 1799-1830", *Scientometrics*, vol. 1, 133-149.

D. deB. Beaver & R. Rosen (1979b): "Studies in Scientific Collaboration: Part III – Professionalization and the Natural History of Modern Scientific Co-authorship", *Scientometrics*, vol. 1, 231-245.

A.J. Meadows & J.G. O'Connor (1971): "Bibliographic Statistics as a Guide to Growth Points in Science", *Science Studies*, vol. 1, 95-99.

R.K. Merton (1965): "The Ambivalence of Scientists", in N. Kaplan (ed.), *Science and Society*, Rand McNally & Co., Chicago, 1965, 112-132.

D.J. de Solla Price, *Little Science, Big Science*, Columbia University Press, New York, 1968.

Appendix C

List of Factors That Contribute to the Increase in Co-authored Publications*

*Taken from J.S. Katz & D.R. Martin (1997): "What is Research Collaboration?", *Research Policy*, Elsevier, vol. 26, 1-18.

1. Changing patterns or levels of funding
2. The desire of researchers to increase their scientific popularity, visibility and recognition
3. Escalating demands of the rationalization of scientific manpower
4. The requirements of ever more complex (and often large-scale) instrumentation
5. Increasing specialization in science
6. The advancement of scientific disciplines which means that a researcher requires more and more knowledge in order to make significant advances, a demand which often can only be met by pooling one's knowledge with others
7. The growing professionalization of science, a factor which was probably more important in earlier years than now
8. The need to gain experience or to train apprentice researchers in the most effective way possible
9. The increasing desire to obtain cross-fertilization across disciplines
10. The need to work in close physical proximity with others in order to benefit from their skills and tacit knowledge

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D.J. de Solla Price, *Little Science, Big Science*, Columbia University Press, New York, 1968.

Appendix D

List of Literature that Supports a Positive Correlation between Productivity and Level of Collaboration

C. Balog (1979-1980): "Multiple Authorship and Author Collaboration in Agricultural Research Publications", *Journal of Research Communication Studies*, vol. 2, 159-169.

D. deB. Beaver & R. Rosen (1978): "Studies in Scientific Collaboration: Part I – The Professional Origins of Scientific Co-authorship", *Scientometrics*, vol. 1, 65-84.

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Appendix E

The National Academies on the Environmental Protection Agency

The National Academies is composed of several committees, boards and divisions. The committees charged with appointing a committee to assess and improve efficiencies in R&D at the Environmental Protection Agency (EPA) were the Committee on Science, Engineering, and Public Policy (COSEPUP) and the National Research Council Board on Environmental Studies and Toxicology (BEST). The two groups supervised the appointment of the task force responsible for assessing and measuring efficiency at the EPA – the Committee on Evaluating the Efficiency of Research and Development Programs. The appointed committee was put in charge of answering the questions below, as well as the sub-questions following:

- What efficiency measures are currently used for EPA R&D programs and other federally funded R&D programs?
- Are these efficiency measures sufficient? Are they outcome-based?
- What principles should guide the development of efficiency measures for federally funded R&D programs?
- What efficiency measures should be used for EPA's basic and applied R&D programs?
    - How – and why – should research be evaluated in terms of efficiency?
    - What is a "sufficient" measure of efficiency?
    - What measures of efficiency are "outcome-based", and should they be?

For their study and review, *inputs, outputs,* and *outcomes* were needed for some form of efficiency assessment, per PART requirements. The OMB defines those three metrics as such:

- *Inputs* are agency resources – funding, facilities, human capital, etc. – that support research.
- *Outputs* are activities and/or accomplishments delivered by research programs, such as research findings, publications, exposure methods developed and validated, and research facilities built or upgraded.
- *Outcomes* are the benefits resulting from a research program, which can be short-term, such as an improved body of knowledge or a comprehensive science assessment, or long-term, such as lives saved or enhancement of air quality that may be based on research activities or informed by research but that require additional activities by many others, otherwise known as *intermediate* outcomes and *ultimate* (or *end*) outcomes.

Appendix F

Research as a Logic Model

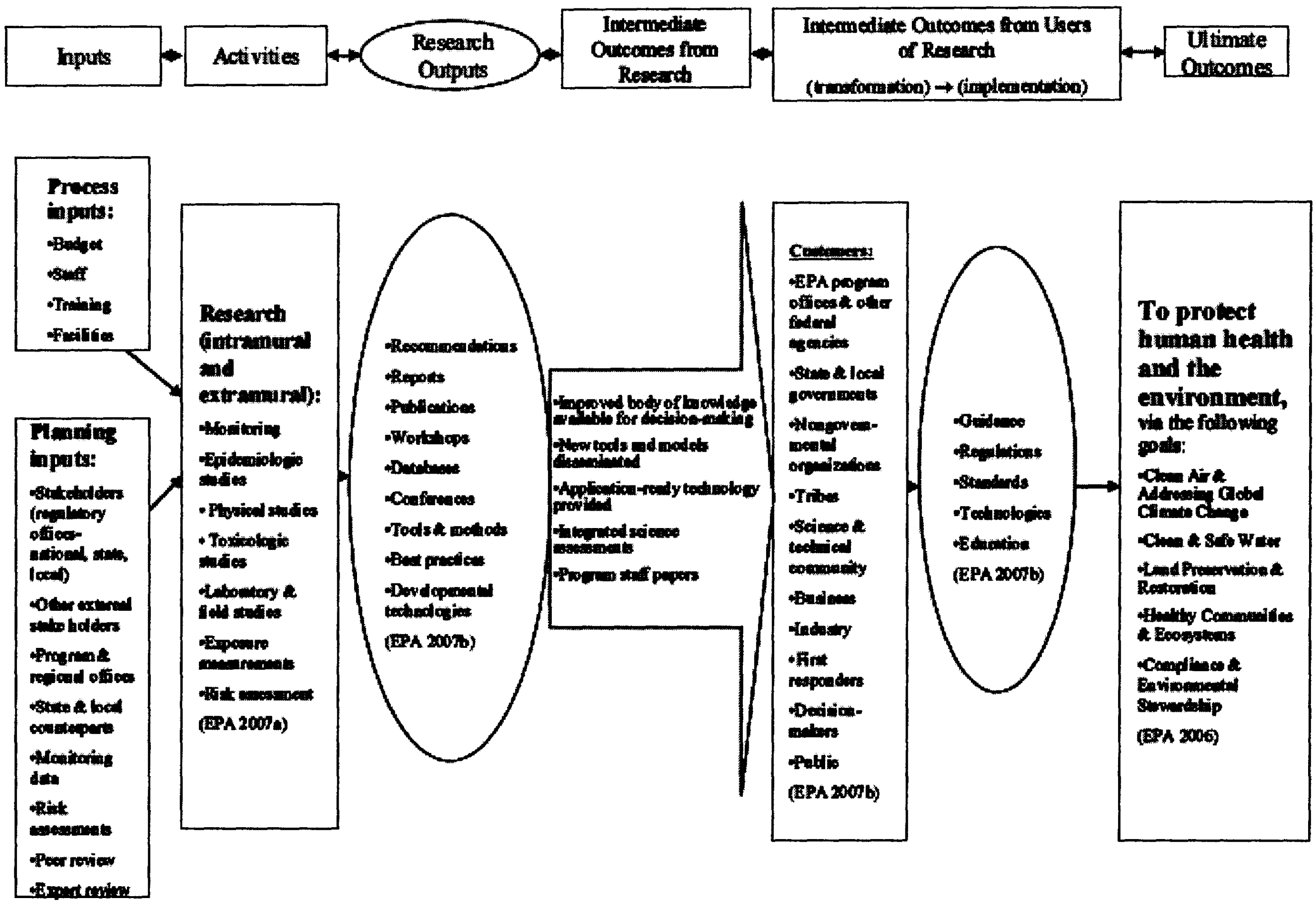

Figure 1: EPA research presented as a logic model.
*Taken from The National Academies, Evaluating Research Efficiency in the U.S. Environmental Protection Agency, The National Academies Press, Washington, D.C., 2008.