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Building Code Assessment Framework

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RÉSUMÉ

Ce document montre l'importance d'élaborer et d'utiliser un cadre d'évaluation des codes qui tienne compte des répercussions techniques, économiques et sociales des exigences des codes du bâtiment. On n'y traite pas des effets d'autres réglementations comme les lois de zonage et les restrictions visant l'utilisation des terres. Le modèle peut toutefois servir à l'évaluation des exigences actuelles des codes et à l'étude de l'impact marginal des exigences nouvelles ou envisagées. On prévoit que l'élaboration du cadre envisagé contribuera à rationaliser les exigences des codes visant à satisfaire aux objectifs donnés des codes du bâtiment.

Building code assessment framework

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This paper demonstrates the importance of developing and using a code assessment framework that takes into account technical, economic and social impacts of building code requirements. The effects of other regulations such as zoning laws and land-use restrictions are not discussed. The model can, however, be used for evaluating existing code requirements and for investigating the marginal impact of new or proposed code requirements that may be adopted in the future. It is expected that the development of the proposed framework will help rationalize code requirements designed to satisfy the given objectives of building codes.

Keywords: Building code regulation, framework, rationalization

1 Background

The National Building Code of Canada, according to the Associate Committee on the National Building Code (ACNBC), is essentially a set of minimum provisions respecting the safety of buildings with reference to public health, fire protection and structural sufficiency. Its primary purpose is the promotion of public safety through the application of appropriate uniform building standards throughout Canada (ACNBC, 1986). Safety and health have been the overriding concerns of building codes. Therefore, economic and cost consequences of these codes to consumers, producers and society as a whole have not traditionally been a major concern either of decision makers or of the general public. The lack of concern for economic impacts was perhaps because of the nature of the regulatory system – a system where decision makers do not pay costs as consequences for their decisions and where those who pay direct costs do not have any influence on the regulatory systems (Runeson and Marosszeky, 1983).

Recently, however, some interest in the economic and social consequences of building codes has been shown. This is due to the progressive proliferation of regulations and their perceived burden on the various actors involved in the building industry, and on society as a whole.

Large increases in housing prices in the 1970s and early 1980s led some researchers in the United States to view restrictive building codes as one of the possible factors contributing to housing prices (Noam, 1983). The review of building codes has also been called for because of the recent deregulation drive (going on in Europe and North America) which proposes to give market forces free play and thus to obtain economic efficiency and better utilization of scarce resources.

1.1 *Economic and social aspects of regulations*

There are basically two types of regulations – economic (old-style regulation) and social (new-style regulation). While all regulations are essentially 'social' in that they affect human welfare, the economic/social distinction emphasizes very important differences. Economic regulations typically focus on markets, rates, etc., while social regulations, on the other hand, focus on the condition under which goods and services are produced, maintained and sold (Lilley and Miller, 1977).

Social regulation is typically conducted by prohibition, by imposition of either performance or design standards (as is the case with the building codes), and by mandatory disclosures of provision or information. The use of standards in the field of social regulation generally has the effect of hiding the costs of such regulation.

Another important characteristic of social regulation is that it involves some aspects of human health or safety. The building codes and fire codes are typical examples of social regulation. Economic assessment of health and safety components of these codes is difficult and has rarely been used as a decision criterion.

1.2 *Rationale for building codes*

The primary rationale for building codes is the *information cost* that the individual consumer (home-owner) would have to pay for knowing the safety, health and comfort characteristics or physical properties of the dwelling. In the absence of building codes, the consumer might be forced into a trade-off between cost of dwelling and level of risk from safety and health points of view. 'The imposition of building codes involves a sufficient saving of resources in establishing the safety level of various building features (as well as possible savings from induced efficiencies in construction) to compensate consumers from any resultant constraint in choosing features of the dwelling they purchase or rent' (Silver and Chagaralamudi, 1980).

When information available to owners/builders is inadequate or too expensive to obtain, there is a question of how far the government should go in rectifying the deficiencies. There are two basic approaches that can be used to remedy this situation: (i) requiring the provision of accurate information; and (ii) licensing of, or setting of standards, for those who have the information that is necessary to make rational decisions.

Another rationale for the existence of building codes is their external or spillover effects. External effects occur when public costs and social costs (i.e. cost to society as a whole) of a product, process, or standards, diverge from those of private costs (similarly between public benefits and private benefits). For example, extensive air and water pollution reflect the fact that firms do not have to pay the full cost of disposing of their wastes. With few exceptions, there are no property rights in the use of the air, water, etc. for the disposal of unwanted industrial by-products.

The rationale for building codes is not without impacts on various actors (owners, builders, etc.). These impacts may be technical, economic, or social in nature. They may be in the form of benefits (e.g. reduction in building costs, increased level of safety, reduction in information costs, reduction in redundancy of overlapping of codes), or costs (increases in initial construction costs and operating costs, etc.). All these benefits and costs must be considered when evaluating the introduction of new provisions into codes or changes to existing provisions.

1.3 *Previous building code impacts/burden studies/models*

A few studies have already been undertaken dealing with either 'building code impacts' or with 'building code burdens'. None of them, however, is truly comprehensive nor designed for the analysis of existing code requirements. Most of these studies have been undertaken in the United States, one in Denmark, another in New Zealand, and one in Canada. The objectives and methodologies used by these studies are described below.

One of the most comprehensive studies dealing with the building code burden was undertaken by Charles G. Field and Steven R. Rivkin (Field and Rivkin, 1975). The findings of this book are based on a survey of 250 home manufacturers and 1000 local building officials. It deals with the prohibitive nature of building codes, especially local codes. The main conclusions of the book are:

- (1) code regulations are perceived as a problem by housing innovators, i.e. obstructive to new building technologies;
- (2) the existing pattern of building codes results in unnecessarily higher building costs and house prices;
- (3) the regulatory system restricts the introduction and diffusion of innovations into the market place;
- (4) socially, undesirable consequences result from the present regulatory structures, i.e. discrimination against lower-income families.

From the survey of manufacturers, the study found that the majority of the firms experienced added costs as a result of the incidence of stricter standards. It cited several previous studies that also found added code burden on construction firms, ranging from 2% to 10% of construction costs.

A study by Stephen R. Seidel (1978) found that building codes, along with other government regulations, resulted in significant price increases and a reduced number of new housing units. Building codes contribute to two types of costs: those associated with the disruption of the free market and those related to administrative inefficiency in implementing codes. In addition, they were found to inhibit innovation. Results of the survey also indicated that government-imposed regulations were found to be the most significant business problem.

A study by McConnaughey (1978) of the U.S. National Bureau of Standards was the first to provide a taxonomy of an analytical framework for calculating impacts of building codes. It clearly identified three types of impact: (1) building code system impacts, (2) income distribution impacts, and (3) benefit-cost impacts. This study illustrated the use of the proposed analytical framework (mostly cost-benefit analysis) with a case study.

In 1981, the National Bureau of Standards published another study (Rawie, 1981) that exclusively deals with the analytics of estimating economic impacts of building code changes by using benefit-cost techniques. It provides a guide for the use of the benefit-cost approach to obtain the greatest public protection for the construction dollar. It argues that, given the needed data, economic analysis can help identify the less costly ways to obtain a desired level of safety.

More recently, another NBS study (Ruegg and Fuller, 1984) has developed a decision model for evaluating the cost-effectiveness of providing fire-loss protection in houses through the use of automatic sprinkler systems. The benefit-cost model of investment decision, as it relates to home-owners, is illustrated with hypothetical examples.

Following on the McConnaughey study, Bonke and Pederson (1983) elaborately outline the code objectives and explain in a systematic fashion how these objectives are fulfilled by various provisions of building codes. The categorized building code requirements for the purpose of undertaking a consequence analysis of indoor climate with regard to air quality in single family homes.

A study in New Zealand (Tippett and Porteous, 1980) describes the first stage of a research project on the cost impact of standards. It presents the findings from a pilot study of one national standard and its impact on delivery cost for two multistorey development projects:

Product cost impact (material and labour costs).

Process cost impact (planning, development and execution costs).

User cost impact (maintenance and repair costs).

Systems and industry cost impact (compliance costs).

The Economic Council of Canada (ECC) working paper (Silver and Chagaralamudi, 1980) is the only study that suggests an exploratory 'holistic' approach to the assessment of building codes impacts. The ECC study provides an economic rationale for building codes. It also discusses distortions created by building codes. Alternatives to building codes, which may promote the same ends, are discussed too. The study puts forward the analytical framework of benefit-cost analysis for the assessment of codes. To determine the impact of building codes on the whole system, the study recommends comparing situations under the present building code system with those which might be expected under the free market system.

1.4 *Why another study?*

Broadly, the foregoing studies can be classified into two types: descriptive and analytical. Among the descriptive type can be put the studies by Field and Rivkin, and Seidel. The conclusions of these studies are based on impressions and opinions obtained through surveying builders, owners, construction firms and material suppliers. These studies, thus, lack the analytical framework for evaluating building codes. The studies of the second type (viz., NBS, Danish, New Zealand studies) do provide an analytical framework, but fail to provide the rationale for building codes. Even their proposed analytical methodology is not complete and comprehensive. Also, the role of risk analysis is not thoroughly explored. Certain analyses advocated by these studies require the use of data and techniques which are non-existent. The individuals and industry sectors to be affected by building code requirements are not properly identified. The hierarchy of code goals and objectives against which all proposals must be measured is not always established.

Also, these studies fail to provide the framework for determining the problems of existing building codes. The ECC study falls in between descriptive and analytical studies. It does raise questions about the rationale of building codes, but fails to provide a specific framework for assessing them.

As demonstrated, the existing frameworks and models display a variety of defects and shortcomings which preclude their straightforward adoption or adaptation for the critical and comprehensive review of building codes. The objective of this paper is to develop a basic framework for code assessment which is more comprehensive and is applicable to existing codes.

Goals, objectives and characteristics of the framework are summarized below. The framework itself is described in detail in the next section.

2 Framework

The main objectives of the framework are:

- (1) To determine and to clarify the objectives and mandate of building codes.
- (2) To assess the technical, social and economic impacts and the risks associated with specific code requirements.
- (3) To rationalize the contents of the building code through modification or elimination of those requirements that are unnecessary, overly restrictive, socially undesirable, economically burdensome, or beyond the code's mandate.

Different components in this framework are:

- (1) Building Code Goals/Objectives Hierarchy Structure
- (2) Building Code Requirements Impacts
- (3) Performance Measures
- (4) Data Base
- (5) Risk/Sensitivity Analysis

2.1 Building code goals/objectives hierarchy structure

The reasons for developing a goal/objectives hierarchy structure are several:

- (i) to break down the overall goal of building codes (public health and safety) into a series of detailed objectives, down to a level at which one can directly relate a particular clause in the code to an objective;
- (ii) to develop an Objectives Interaction Matrix (at a detailed level) for detecting duplications and conflicts in the existing building codes;
- (iii) to identify the type of information that may be needed for the assessment of different code requirements;
- (iv) to identify evaluation methodologies for assessment of different code requirements.

Figs 1 and 2 depict the objective hierarchy structure for the code objective 'health'.

In order to be able to assess the consequences of a particular requirement in the code, it has to be considered in the code context. For example, a particular fire prevention clause should be assessed in the context of all other fire prevention/protection clauses. For this purpose, all building code clauses should be grouped under different code objectives (at design objectives level, level 4).

For the proper assessment of the requirements, the relationship between different objectives needs to be identified. An Objective Interaction Matrix is developed to achieve this purpose (Fig. 3). This figure shows the interaction between different design objectives (level 4).

Figure 3 also shows that a code requirement may relate to more than one objective (e.g. room size is related to health requirements as well as comfort). Furthermore, requirements that satisfy one objective may have some effect (positive or negative) on the performance of the building with respect to other objectives (e.g. fire confinement v. ventilation, air quality).

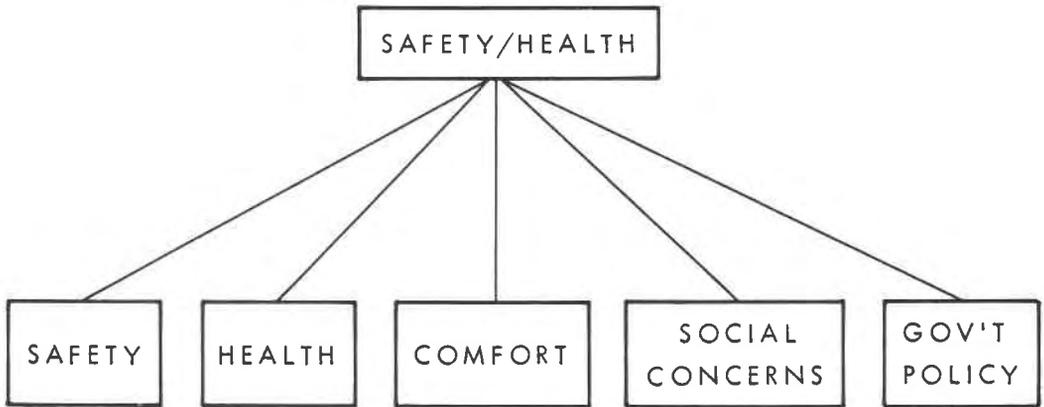


Fig. 1. Breakdown of the overall building code goal.

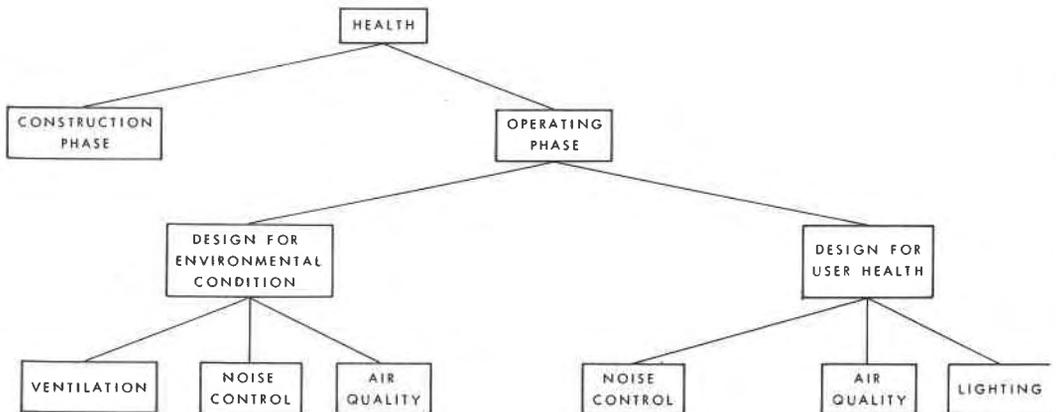


Fig. 2. Breakdown of objective 'health'.

2.2 Impacts of building code requirements

The impacts of the building code requirements can be viewed from different perspectives. The builder may be interested in building code requirements that limit his choices and increase the building cost while the owner/occupant is concerned with safety requirements. Labour may be concerned with the impact of code provisions on employment while the manufacturer is concerned with the limitations on the use of raw material, manufacturing processes and new requirements for testing and standards. Systematic determination of these impacts requires the proper identification of:

- (i) impact groups
- (ii) fields of consequence.

The 'impact group' includes individuals who are involved in building projects (developer, owner, builder, designer, supplier, regulator, etc.) and industry sectors that are affected by building regulations (real estate, manufacturing, insurance, etc.).

The 'fields of consequences' are divided into two categories: 'technical consequences' and 'socioeconomic consequences'. Tables 1 and 2 provide a detailed breakdown of these two categories.

2.3 Performance measures

In order to measure the impact of code requirements, one needs to define an appropriate set of performance measures that reflects the code objectives. These performance measures can be categorized in three sections:

- (i) Technical performance measures,
- (ii) Economic performance measures, and
- (iii) Social performance measures.

The technical performance measures will be used in evaluating the impact of code requirements on the technical performance of buildings; the economic performance measures will be used in measuring the economic impact of code requirements on the impact groups; and the social performance measures will address the issue of code requirements impacts on the environment, people and other sectors of society. The performance measures include qualitative measures such as accessibility and user comfort as well as quantitative

Table 1. Technical consequence breakdown.

Technical consequences			
Building process	Planning/projection Design	Limitation of choice	
		Engineering design	
		Architectural design	
	Construction	Productivity	
		Equipment	
		Material	
	Operation/maintenance		Safety/protection
			Energy consumption
			Operating policy
Maintenance policy			
Safety			
Health			
Material/equipment	Raw materials	Material limitation	
		Availability	
		Standards	
	Manufacturing	Performance	
		Availability	
		Design information	
	Quality/safety assurance	Warranty Certification	Demand for new warranties
			Demand for standards
		Code enforcement	Demand for testing procedure
Demand for inspection policy			

Table 2. Socioeconomic consequence breakdown.

Socioeconomic consequence		
Economic	Design phase	Design fee
		Plan approval cost (government)
		Plan approval cost (owner)
	Construction phase	Material cost
		Labour cost
		Equipment cost
		Building inspection cost
		Certification cost
		Financing cost
	Occupancy phase	Administration cost
		Operating cost
		Maintenance cost
		Upgrading cost
		Insurance cost
		Taxes
Social		Environment
		Employment
		Distribution impact
		Accessibility
		Energy conservation

measures such as energy consumption and probability of fire-related injuries. Since the useful life of buildings (or their components) extends beyond their construction period, it is essential to consider the impact over a long period of time (e.g. 15–20 years) and, in doing so, to consider the time-related factors such as time value money, inflation, and the effects of ageing of buildings.

The following is a sample of the performance measures that may be used in the code assessment framework.

Technical performance measures

- Probability of structural failure
- Probability of fire
- Probability of health hazards
- Energy consumption level
- Flexibility in use

Economic performance measures

- Life cycle cost
- Costs and benefits
- Productivity (labour, equipment, material)

Social performance measures

- Accessibility
- Comfort and user satisfaction
- Environmental pollution

2.4 Data base

The availability of a reliable data base for testing or working with any framework is as important as the framework itself. For evaluation purposes information about the technical performance of buildings and other health and safety related requirements can be obtained from various sources.

Sources of the required data. Basically, there are three situations:

(i) Published information exists (e.g. fire-related statistics) and they only need restructuring or refinement.

(ii) The information exists in different organizations, but in unorganized and unpublished forms. In this case, efforts will be made to investigate, collect and develop a data base. Also, as part of this exercise, a permanent system of data collection will be established.

(iii) Technical information exists but is not available. In this case a bank of technical experts in different code-related subjects will be developed. The information will be collected through questionnaires or through other feasible means such as the Delphi method.

2.5 Risk analysis

One of the main objectives of developing the Code Assessment Framework is to enable the decision makers in the code advisory committees to make better-informed decisions by providing them with additional information about the impact of building code requirements, especially where the assessment is subjective. The final outcome of impact analysis would not be certain. The uncertainty will creep into the analysis because of various assumptions made regarding certain parameters and insufficient or unreliable data used. For example, analysts or members of a technical committee may have different assumptions about the impact of an additional fire safety regulation in reducing the number of fire-related deaths or injuries. These subjective assumptions may or may not be of critical significance in the assessment of a particular code requirement.

There are also uncertainties regarding the scope or quantity of things (e.g. number of bricks, pounds of steel, man-hours) and the unit cost of things at the time when these costs are actually incurred. There are also uncertainties regarding the timing of actual occurrence of these costs. The risk analysis will expose the significance of uncertainties associated with various assumptions and quantities and costs of impacts.

The two leading approaches to uncertainty assessment are: the deterministic approach (e.g. sensitivity analysis) and the probabilistic approach (e.g. probability analysis). Sensitivity analysis, in the sense of response to variations, can be of two types: quantitative and qualitative. Quantitative sensitivity is defined as the numerical measure of changes in output to variations of input (parameters). The qualitative aspect of sensitivity analysis deals with model design. It refers to the capability of a model to respond to dynamic changes in the subject being modelled.

The sensitivity analysis is performed by varying different values of inputs (or parameters) and thereby obtaining different values for corresponding outputs. In this way, upper and lower bounds of output can be established.

Probability analysis relies on the use of probabilities rather than the repetition of the evaluation process (as is the case in sensitivity analysis). It is useful when (i) there is more than one possible condition or 'state of nature' that can occur; (ii) the outcome of the project may

differ depending on the state that occurs; and (iii) the probability or the relative frequency with which each possible state is expected to occur can be used to calculate the average, or 'expected', value of possible outcomes weighted according to their frequency of occurrence. With the help of probability analysis, different alternatives with different states and probabilities can be compared to each other, or non-deterministic risk analysis techniques may be used.

The risk analysis procedure can be as sophisticated as the available data bank allows. Some situations may lend themselves to the use of probability distributions, while others may be limited to simple three-point estimates of pessimistic, mean and optimistic expectations. Although remarkable advances are possible (and anticipated) in risk analysis of building industry problems, the nature of the industry probably precludes it from reaching the high degree of precision attained in modern high-tech industries such as space technology. Building industry participants are not yet able to play their respective roles in design, manufacture, construction, maintenance, or use, with a degree of sophistication that will allow a comparable degree of precision and uniformity. Hopefully this situation will rapidly improve.

3 Illustrative example

This example is a hypothetical illustration of how the assessment model might be applied in a practical situation. For this purpose we have chosen the general area of fire safety requirements. This is one of the most comprehensive and fast-growing sections of the building codes. Unfortunately this growth is mainly a reactive (and possibly unreasoned) response to fire accidents. In general, it is not the result of well-directed research regarding fire safety nor is it the strategic accumulation of informative experiential statistics regarding fires, e.g. configuration of the building, type of construction, level of compliance with the code, facilities that were useful in limiting or extinguishing the fire, etc. As a consequence there is a general feeling that requirements have increased without proper justification and on an *ad hoc* basis.

As an example, consider the case of the requirement for 'fire-hose cabinets' in large buildings. They cost hundreds of thousands of dollars to install and equip – but are they effective? Do occupants use them? Do they cause accidents and damage? Do fire fighters use them? Do they create a false sense of security? In short, are they worthwhile or are they wasteful?

The problem is complex. Many issues must be considered and much data assembled. In the first place, true to the basic tenets of the model, the issue must be looked at in context. In this case, this means a review of the 'fire confinement' area of the code in which the provision of fire-hose cabinets is one of the requirements. How do fire-hose cabinets contribute to fire safety objectives? What is their marginal contribution to the cumulative impact of the combined requirements? Are other requirements more effective or more cost-effective?

In this example, the Complementary Code requirements with respect to fire confinement are:

- Fire resistance ratings
- Fire separation ratings
- Fire spread ratings

Sprinklers (regular/fast response)
 Hose cabinets
 Standpipe water supplies
 Portable extinguishers

Obviously, several carefully selected evaluation criteria are required. In our hypothetical example the following criteria are used:

Probability of fire
 Probability of death per fire
 Probability of injury per fire
 Probability of damage per fire
 Probability of safe evacuation
 Average damage cost per fire
 Life-cycle cost (20 years) (owner)
 Life-cycle cost (industry)

Obviously other criteria could be used as well, such as cost to regulatory agencies.

One may obtain a grasp of how the framework requires the analysis to be carried out by examining Table 3. This table shows the type of information that would be required for the analysis and how it would be used to derive decision-making results. The table is a matrix of quantified evaluation criteria versus cumulative code requirements. It provides the supporting data for subsequent steps in the analysis process. If an analyst wished to obtain the probable cost of a fire in a particular type of building, he would multiply the probability of fire by the average damage cost per fire. If he wished for the total expected fire costs for this type of building, he would multiply the previous result by the number of buildings of this type.

The information in the table is not factual but is reasonably realistic. Since there is no existing data bank of cost or technical information, we are unable even to speculate as to the total economic impact of the requirements (note the many question marks). These question marks dramatically demonstrate the need for development of a complete and comprehensive data base. Reliable decision making is directly dependent on the input of adequate supporting information. Unquestionably, a large amount of information must be assembled to carry out a complete analysis. Some of the input data required for this example are:

Total number of buildings that are (will be) affected by a code requirement.

Total number of reported fires in this building category.

Number of deaths and injuries in these fires.

Type of construction, and fire-safety features in buildings with fire accidents.

Marginal impacts of the complementary code requirements (using simulation models similar to those developed by the NBS):

increasing costs

reducing the risk of fire/death/injury/damage.

Table 3 shows how each additional code requirement reduces the risk of hazard in buildings. Note, however, that it indicates that the addition of requirement 5 (fire-hose cabinets) not only does not significantly decrease the risk of fire or death but it increases the risk of injury. An injury could result from the improper use of such a facility in a panic situation. Even at this stage, our hypothetical example implies that the provision of fire-hose

Table 3. Cumulative impact of fire confinement regulations contained in the building code.

Typical evaluation criteria	Code requirements						
	(1) Fire resistance ratings	(2) (1) + Fire separation ratings	(3) (2) + Flame spread ratings	(4) (3) + Sprinklers	(5) (4) + Hose cabinets	(6) (5) + Standpipe water supplies	(7) (6) + Interior design requirements
Probability of fire	0.008	0.008	0.008	0.006	0.006	0.006	0.006
Probability of death per fire	0.007	0.006	0.004	0.002	0.0018	0.001	0.0008
Probability of injury per fire	0.04	0.37	0.03	0.02	0.025	0.018	0.015
Probability of damage per fire	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Probability of safe evacuation	0.8	0.9	0.95	0.98	0.98	0.99	0.998
Average damage cost per fire	?	?	?	?	?	?	?
Cost to owner (over 20 years)	?	?	?	?	?	?	?
Cost to industry	?	?	?	?	?	?	?

cabinets results in no significant increase in fire safety and that their cost is unwarranted in this particular case.

The next step in the analysis would be to examine alternative combinations of requirements. In one of these combinations, fire-hose cabinets might prove to be cost-effective. The essential point is that no individual requirement should ever be considered in isolation. The overall cumulative impact of any combination of requirements must always be determined.

The full analysis of the fire-hose cabinet requirement would require the completion of an impact analysis as outlined in this paper.

4 Concluding remarks

The paper has outlined the framework for technical and economic evaluation of the building codes in Canada. The proposed framework is designed to provide a practical, comprehensive decision-making tool that is capable of evaluating code requirements with respect to their goals and objectives. The framework is also capable of identifying different actors involved in a building project (owners, users, architects/engineers, contractors/subcontractors, governments, etc.) and the different sectors of the industry (construction, manufacturing, real estate, insurance, etc.) that are affected by building codes. The ultimate success of the proposed framework will depend on the availability of technical and economic data.

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