Use of System Dynamics to Understand Long-Term Impact of Climate Change on Pavement Performance and Maintenance Cost

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An increase in the vulnerability of the nation's roadway network to changes in climatic conditions has become an issue of significant concern. Heavy rainfall and high temperatures are examples of climatic factors that can affect pavement performance and conditions in a detrimental way. Some of these effects, specifically on costs associated with constructing and maintaining roads, may not be significant in the short term but may become significant in the long term. The objective of this study was to present a framework to use system dynamics to understand the long-term impact of climate change on pavement performance and maintenance activity. A system dynamics model was created with available pavement performance and climate change data, and the effects on various key factors, such as pavement life and maintenance cost, were evaluated through simulation. Preliminary results show that the long-term effects of changes in air temperature, rainfall, seawater-level rise, and number of hurricanes on pavement performance are significant and that costs are expected to increase significantly (>160% in 100 years) and nonlinearly. From these findings, recommendations are made for obtaining more accurate and reliable data on relevant climate change factors and for using a system dynamics approach to integrate the multidisciplinary topics of climate change, pavement design and performance, and economics into comprehensive studies.

Research has shown, and continues to show, that the nation is becoming increasingly vulnerable to devastating damage to the infrastructure as a result of changing global climatic patterns, for example, floods associated with hurricanes of increasing frequency and rise in seawater and ground water levels (1-6). The Intergovernmental Panel on Climate Change (IPCC) has stated that the frequencies of heavy precipitation, as well as rainfall from tropical cyclones, are likely to continue to increase in this century (7). Evidence from three recent hurricanes, Katrina, Irene, and Sandy, in the United States strongly supports the research findings; the resulting floods would affect much of the coast and millions of residents. As projected by the IPCC, rising sea level is virtually certain (>99% probability of occurrence) to continue, and increases in intense precipitation events are highly likely (>90% probability of occurrence) to become more frequent in widespread areas of the United States (8). As a consequence, along coastal areas and low-lying river areas, flooding will be expected to occur more frequently, such as in the Midwest along the Mississippi River (9).

Pavements constitute the most widely used part of the nations' infrastructure for the transportation of people and goods. An increase in pavement temperature as a result of rising air temperature, reduction in subgrade and hot-mix asphalt (HMA) modulus as a result of high rainfall (saturation), and flooding as a result of rising seawater levels (in coastal areas) and hurricanes can inflict significant damage to pavements, making them unserviceable and causing a major negative impact on the nation's economy. The ingress of moisture in pavements from flooding can also accelerate the onset of other types of distress, such as rutting and cracking.

The impact of change in climate on pavement performance has been investigated by a few researchers (10-12). Meagher et al. presented a methodology to assess the impact of climate change on pavement deterioration (13). Instead of using historic (stationary) data sets, they conducted a mechanistic-empirical analysis of pavement structures (designed for four sites across New England) with predicted future temperatures and evaluated their effects on the rutting performance of the pavements. The effect on the rutting potential of the HMA layer was significant. The authors demonstrated and proposed the concept of downsizing regional climatic model temperature data sets to create modified hourly climatic files in the Mechanistic-Empirical Pavement Design Guide (MEPDG) and software.

Increased damage in pavements will definitely lead to more rapid deterioration of pavements, reduction in pavement lives, and increased maintenance cost. The United States spends nearly $200 million a day building and rebuilding roads and bridges; more rapid deterioration as a result of climate change will increase this amount. Already overburdened pavement maintenance and repair budgets will be stressed even further, and the changing climate will likely require new approaches to pavement design, maintenance, and management. This paper presents a framework for a methodology that can be used to answer one of the most relevant questions for the development of new ways to manage and maintain pavements: What will be the impact of future climate on pavement life and maintenance costs?
SYSTEM DYNAMICS

System dynamics is an approach that helps develop a strategic view of a system, which could be an industry, society, or nation, by modeling the different parts and simulating the dynamics of interaction among the different parts. Modeling helps to determine changes over time and develop a view that cannot be obtained from spot studies conducted with a few of the critical elements of the system or within the confines of a specific time (e.g., second, hour, day, or year). One of the most powerful elements of this approach is the ability to link elements and model the interdependencies of the various elements across disciplines (e.g., climatic science and civil engineering). Known as causal (or feedback) loops, these links help researchers understand the dynamic nature of a problem and simulate the systems over time.

The important aspect of simulating over time is that whereas impacts (such as that of unsustained growth in population or construction) may appear to be linear over a short time (e.g., 5 years), in reality, they may be exponential over a decade or a few decades. Having the ability to view this change over a long time period is essential for developing policies for an industry, society, or nation and to make sure that the far-reaching consequences of adoption of these policies are indeed beneficial in the long run. This ability can help differentiate good policies from bad policies. Policies may appear to be good in the short term but in the long term may have disastrous consequences, and only a proper system dynamics model can capture this result.

Another key aspect of the system dynamics approach is the ability to show the root cause (or causes) of a problem. A good system dynamics model can include all of the essential elements and their interdependencies and hence, the relational dynamics.

The steps in the modeling of system dynamics consist of identifying and defining a problem; developing a dynamic hypothesis; and modeling, simulating, and developing policies and evaluating them. The components of a typical system dynamics model are stock, flow, and connectors. Stock represents a commodity that can increase or decrease in value or number or quantity. Flow is the rate of increase or decrease in the stock, which can be influenced by connectors. An example is if the amount of available natural aggregate can be considered a stock, the amount of use of aggregate in tons per kilometer of a road can be considered a connector. The connector dictates the rate of flow, which can be the same as the rate of use of aggregates or can also be influenced by the amount of recycled aggregates.

System dynamics has been used since the 1960s in modeling and simulation of problems in a wide range of areas, including society, industry, sustainability, food, population growth, and natural resources. Forrester (14) introduced the subject through his sustainability model on world dynamics, and was followed by Meadows et al. (15), who presented the limits to growth model. Meadows et al. have updated the study twice (16, 17). A model to illustrate the unsustainability of civilization was presented by Sierman (18). Sierman studied growth, carrying capacity, and technology, as well as the delays in regeneration of resources, development of technologies, and adoption of policies. The carrying capacity of the earth system and detrimental effect of unsustainable growth on the environment has also been investigated with system dynamics modeled by Radzicki (19), Bueno (20), and Bockermann et al. (21). System dynamics has been used to investigate the relationship between quality of life and sustainability by Beck and Stave (22, 23), and Grosskurth (24) looked at a case study on regional sustainability in the Netherlands. Models for the forecast of fossil fuels have been developed by Maggio and Cacciola (25), and the link between resource productivity, consumption, and sustainability has been investigated by Schmidt-Bleek (26).

OBJECTIVE

The objective of this study is to develop a framework or methodology to use system dynamics to understand the long-term impact of climate change on pavement performance and maintenance activity.

MODELING AND SIMULATION

The overall pavement analysis approach and its consideration in the model are shown in Figure 1. A system dynamics model linking climatic changes to pavement maintenance and costs was developed, as shown in Figure 2. The connectors, in the form of equations, and the parameters are explained in Equation Box 1. The increase in cost of maintenance was determined on the basis of increase in thickness of HMA that is required to maintain the deteriorated roads. Because paving for maintenance depends on the fraction of the roads needing maintenance, as the latter increases, the cost should also increase. However, note that the term “maintenance” has been applied for both maintenance and rehabilitation because maintenance is assumed to be applied for roads that have exhausted their structural performance lives as predicted by the MEPDG software. The scope of improvement in this analysis (beyond the scope of this paper) differentiates between surface distress maintenance and structural rehabilitation. In this case, the rate of use of HMA per lane km has been calculated on the basis of an average of 75-mm-thick HMA (between 50 mm of maintenance overlay and 100 mm of rehabilitation layer), with a density of 2,355 kg/m³.

This paper uses a single pavement cross section with rutting as the primary distress to illustrate the power of using a system dynamics approach. A two-lane highway, which lies along the coast of New Hampshire, was selected as the model road. To represent changes in climate, four factors were considered: (a) rise in air temperatures, which cause a rise in pavement temperature and decreased modulus of HMA; (b) increase in average annual rainfall, which affects duration for which the subgrade soil can be expected to be at or close to saturation, and hence affects the modulus of the subgrade soil; (c) increase in seawater level; and (d) increase in number of Category 3 hurricanes. The third and fourth factors are expected to increase the number of inundation (flooding) occurrences, and hence cause a lowering of the modulus of HMA and subgrade. The single pavement structure was analyzed for a range of temperatures and subgrade moduli values, to evaluate the effect of these climate changes on its rutting life (i.e., years to failure by rutting).

Climatic Factors

The climatic data used in this model were obtained from the U.S. Geological Survey (27). The climate data include two 30-year periods, 1970 to 1999 and 2040 to 2069. The GFDLCM2.0 general circulation model from the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce was dynamically downscaled using the RegCM3 regional climate model. RegCM3 is a high-resolution atmospheric model coupled with a physical model of surface processes. The atmospheric composition in the RegCM3 simulations
match the 20th century and A2 scenario time series that were developed for the IPCC Fourth Assessment Report and used in the driving general circulation models (8). A grid cell located in Massachusetts was used for the analysis (latitude 42.12946 north, longitude 72.10891 west). In the model, two parameters were used for the variables that are dependent on the climatic factors: an initial value and a rate of change per unit change in the specific climatic factor.

Temperature

The daily average air temperature record (average and maximum air temperature) were analyzed for the two 30-year periods (1970 to 1999 and 2040 to 2069). The 30-year average value for each day of the year was determined for both periods. Average daily temperature differences were calculated for each day of the year and then averaged for the entire year, resulting in an average temperature change projected to occur in 70 years. A linear increase over time was assumed. On the basis of these data, an increase in maximum air temperature of 0.024°C per year was predicted and used in the maximum pavement temperature versus maximum air temperatures model (LTTP model) to estimate a coefficient of change in the maximum pavement temperature per degree change in the maximum air temperature.

In this initial systems analysis, the projected climate is simplified. A single location with one climate model, one emissions scenario, and a constant rate of change was used to provide estimates of climate data. Extending beyond a single model and scenario is recommended because there is considerable uncertainty in the climate factors. Sources of uncertainty result from unknown relationships between climate and atmospheric concentrations, seasonal differences, difference among model physics and parameterization, and future carbon emissions, which depend on human activities. Relative to recent regional studies that have evaluated ensembles of models under different emission scenarios, the values used in this study are not unreasonable. The temperature increases are similar to the ensemble average values, but the precipitation values are somewhat higher than those found by Hayhoe et al. (28). Hayhoe et al. provide insight to the uncertainty that might be expected in the northeastern United States. They found an approximately 20% increase in temperature for the higher A1F1 scenario and a 15% decrease in temperature for the lower B1 emission scenario. The annual temperature change
FIGURE 2  System dynamics model.
EQUATION BOX 1  Equations Used in System Dynamics Model

Hot_Mix_Aspalt(t) = Hot_Mix_Aspalt(t - dt) + (-Hot_Mix_Aspalt Use Rate) * dt
INIT Hot_Mix_Aspalt = 1e + 20 tons (this number has been chosen arbitrarily)
OUTFLOWS: Hot_Mix_Aspalt Use Rate = Annual Km Paved * Hot_Mix_Aspalt Use Per Km

Number of Inundations per Year(t) = Number of Inundations per Year(t - dt)
+ (Increase in Number of Inundations per Year) * dt
INIT Number of Inundations per Year = 0.267 + 1 * 0.150
INFLOWS: Increase in Number of Inundations per Year = 10.695 * Rate of Change in Sea Water Level + 1
Rate of Increase in Number of Flood Causing Hurricanes

Roads Needing Maintenance(t) = Roads Needing Maintenance(t - dt) + (Deterioration - Paving for Maintenance) * dt
INIT Roads Needing Maintenance = 50 (this number has been chosen arbitrarily)
INFLOWS: Deterioration = New Roads/Average Pavement Life Adjustor
OUTFLOWS: Paving for Maintenance = Roads Needing Maintenance * Fraction of Roads Maintained

Maximum Pavement Temperature(t) = Maximum Pavement Temperature(t - dt) + (Temperature Increase) * dt
INIT Maximum Pavement Temperature = 58 (maximum temperature at project location)
INFLOWS: Temperature Increase = 0.78 * Rate of Change in Maximum Air Temperature

Months with 100% Saturation(t) = Months with 100% Saturation(t - dt) + (Increase in 100% Saturation Months) * dt
INIT Months with 100% Saturation = 2
INFLOWS: Increase in 100% Saturation Months = (0.0071 * Rate of Change in Average Annual Rainfall)

New Roads(t) = New Roads(t - dt) + (Paving of Rehabilitated Road + Paving for Maintenance - Deterioration) * dt
INIT New Roads = 0
INFLOWS: Paving of Rehabilitated Road = Authorized Rehabilitations Kms Per Year Paving for Maintenance
Paving for Maintenance = Roads Needing Maintenance * Fraction of Roads Maintained
OUTFLOWS: Deterioration = New Roads/Average Pavement Life Adjustor

Annual Km Paved = Paving of Rehabilitated Road + Paving for Maintenance
Authorized Rehabilitations Kms Per Year = 2

Average Pavement Life = -25.574 + 0.000551 * Effective Resilient Modulus of Subgrade Soil + 0.0000452 *
Effective Inundation plus Temperature Adjusted Modulus of HMA (based on regression equations)

Average Pavement Life Adjustor = If (Average Pavement Life > 1) THEN (Average Pavement Life) ELSE (1)

Effective Inundation plus Temperature Adjusted Modulus of HMA = Temperature Adjusted Minimum HMA Modulus - 0.03
* Number of Inundations per Year + INIT(Temperature Adjusted Minimum HMA Modulus)

Effective Resilient Modulus of Subgrade Soil = 26,500 * (12 - Months with 100% Saturation Adjustor
for Maximum of 8 months)/12 + 8,690 * (Months with 100% Saturation Adjustor for Maximum of 8 months/12)

Fraction of Roads Maintained = 0.1

Hot_Mix_Aspalt Use Per Km = 636 tons (for average of 50 mm maintenance and 100 mm rehabilitation layers)
Increase in Cost of Road Construction and Maintenance % = 100 * (Hot_Mix_Aspalt Use Rate - INIT
(Hot_Mix_Aspalt Use Rate))/INIT(Hot_Mix_Aspalt Use Rate)

Months with 100% Saturation Adjustor for Maximum of 8 months = If(Months with 100% Saturation ≤ 8)
THEN(Months with 100% Saturation) ELSE(8)

Rate of Change in Average Annual Rainfall = 2.8189 mm
Rate of Change in Maximum Air Temperature = 0.024°C
Rate of Change in Sea Water Level = 0.0093 m
Rate of Increase in Number of Flood Causing Hurricanes = 0.000556

Temperature Adjusted Minimum HMA Modulus = 158,8003 - 16012 * Maximum Pavement Temperature

NOTE: Each stock has an inflow and in some cases an outflow as well. These inflows and outflows are controlled by flows, and both stock and
flows can be affected by or can affect converters; INIT = initial; climatic factors are explained in the climatic factors section.
differed across the nine models reviewed by up to 75%. Furthermore, projected temperature and precipitation changes differ by location. For example, the CMIP 3 projected temperature increases are more modest across the southeastern United States and West Coast as compared with other regions (29). Precipitation is projected to increase across the northern United States, but decrease in the Southwest.

Rainfall

An increase in average annual rainfall of 2.8 mm per year was predicted with the same approach described above. Using these rainfall data, researchers modeled soil moisture with a one-dimensional bucket-style model to predict the change in the number of times the soil could be expected to be at or close to saturation (30). The bucket model is a simple model for soil moisture dynamics, which includes pavement wetting, infiltration into the pavement structure, and drainage to field capacity. The model was forced using daily precipitation data for the current and future 30-year study periods for a 1-m-thick subgrade consisting of silty loam soil. Daily soil moisture was used to estimate an increase in the number of days (and hence months) at which the soil will be close to saturation.

Seawater Level

Values for the rise in sea level were estimated from a study by Kirshen et al. (31) that determined local stillwater elevations for Portsmouth, N.H. These values were based on data obtained from the Fort Point station in Newcastle, N.H., and from methodology included in work by Kirshen et al. (31). An increase in seawater level of 0.0093 m per year was estimated. Although inundation will vary by location, according to the available data, a site having a current inundation of once every year might reasonably be expected to be inundated approximately five times annually (during astronomical high tides) for a 40-year future data period. The change in inundation per meter rise in seawater level was determined.

Number of Category 3 Hurricanes

On the basis of currently available historical hurricane data (http://www.aoml.noaa.gov/hrd/hurdat/), the number of Category 3 or higher hurricanes was estimated at 0.15 per year for the current 30-year period. Future 30-year periods were estimated at 0.167 per year, using the estimated 10% to 15% increase in the frequency of high-impact events by Done et al. (32). For each occurrence of a hurricane, an occurrence of inundation was considered for the pavement.

Pavement Properties

Two critical pavement properties were considered for assessing the impact of the changes in climatic factors: resilient modulus of the subgrade soil and HMA. An effective modulus of the subgrade soil was calculated, considering the months at which the soils could be considered to be dry and those at which the soil could be considered to be fully saturated. A 100% modulus was assumed for the soil in the dry months. For the saturated months, a modulus of 30% of that at dry condition was considered, on the basis of data and recommendations from Appendix DD-1 of the MEPDG (33). Finally, a weighted average modulus was calculated on the basis of the moduli and the corresponding months of saturation.

With the MEPDG, the minimum surface HMA moduli were determined for sites with different high temperatures. A linear model relating maximum pavement temperature (calculated from maximum air temperature) to minimum modulus was determined. This modulus was then adjusted for the effect of water through inundation. This approach may not be accurate, but it is used as a practical approach to illustrate the use of a system dynamics framework.

In the case of the effect of inundation on the modulus of HMA, it has been concluded that the duration of the inundation period does not seem to have an effect on the damage to the pavements (34). Therefore, instead of an inundation period, the number of cycles of inundation (comparable to number of cycles of conditioning in the laboratory) was assumed to have a significant effect on the modulus of the HMA. For example, one study showed that the tensile strength ratio of a moisture-susceptible mix dropped from 0.9 to 0.6 from one moisture conditioning cycle to 10, which is a reduction of 0.03 times the strength per cycle of inundation (35). This relationship was used to represent the change in HMA modulus as a function of inundation cycles.

Pavement Performance Analysis

The relationships between temperature and pavement life and subgrade modulus and pavement life were developed using the pavement structure for a two-lane highway in coastal New Hampshire. The MEPDG software, Version 1.1., was used to analyze the pavement structure under different climates and subgrade modulus values. The pavement structure consisted of 3 in. of asphalt concrete (12.5 mm nominal maximum aggregate size, PG 64–28) over 16 in. of gravel, 24 in. of sand, and an A–1–b subgrade. Modulus values and other MEPDG inputs were obtained from the New Hampshire Department of Transportation. Default values were used when specific information was not available. (The thicknesses and moduli values used in this paper are given in U.S. customary units as they have been used in the MEPDG software.)

For this particular pavement structure and traffic loading, rutting was the primary cause of failure in the pavements with increasing temperatures and decreasing subgrade modulus values. There was less than 10% alligator cracking predicted, and the amount of longitudinal cracking decreased with increased temperature and decreased subgrade modulus. Therefore, pavement failure was defined as 0.75 in. of total rutting for the purposes of this project.

The relationship between temperature and pavement life was developed by running the MEPDG analysis of this pavement structure with climate files from cities along the East Coast of the United States. The number of months to a total rut depth of 0.75 in. was determined from the MEPDG output. This time to failure (defined as 0.75 in. total rut depth) was converted to years and then plotted against the maximum pavement temperature determined for that location using the LTPFEBad program. A linear regression was performed to determine the relationship between years to failure and pavement temperature.

To determine the relationship between subgrade modulus and pavement life, MEPDG analyses were conducted using the New Hampshire climate and a range of reduced modulus values. The original modulus value for the subgrade was 26,500 psi. Modulus values of 95%, 90%, 80%, and 70% of the original value were used for MEPDG analysis. The number of years to failure (defined as 0.75 in.
total rut depth) was determined from the MEPDG output and plotted against the subgrade modulus percentage. A linear regression was used to determine the relationship between years to failure and subgrade modulus.

**Results: Climate Change and Impacts**

The model was run for a time span of 100 years, and the results for the example pavement are shown in Figures 3 through 7. As expected, because of predicted changes in the climate, the maximum pavement temperature, the number of 100% saturation months, and the number of inundations do increase over time. The result is reduced effective subgrade modulus, minimum HMA modulus, and average pavement life. For the modeled pavement, the maximum temperature increases by 1.8°C, the number of inundations increases by 10, and the number of months at which the soil is expected to be at or close to saturation increases from 2 to 4 over the span of 100 years. The corresponding change in effective resilient modulus of the subgrade soil is from 23,500 to 20,500 psi, and that for the modulus of the HMA is from 625,000 to 400,000 psi.

Figure 6 shows the most important finding: the change in average pavement life decreases from 16 to 4 years over the span of 100 years.

The net effect of all of these changes is reflected in Figure 7, which shows the percent increase in cost with and without considering the effect of climate change. It can be seen that because of maintenance the overall cost decreases initially, but starts increasing after 20 years for both cases. The case with no consideration of the impact of climate change shows a linear increase, with a positive increase only after 45 years. The case with consideration of the impact of climate change shows a nonlinear increase, with a positive increase after 35 years. At the end of 100 years, the increase in the scenario without the climate impact is below 60%, whereas the increase in the scenario with the climate impact is more than 160%, a significant difference. In these calculations the effect of rising costs has not been considered, and an asphalt mix overlay has been considered as the maintenance activity.

These results depend on the specific pavement and traffic used and the models developed in this study, and the results will change as more accurate models are applied. However, it is clear that the reduction in pavement life is caused by increasing damage that would result from detrimental effects on key material properties (such as modulus) caused by higher temperature, rainfall, seawater level, and more Category 3 hurricanes. The key observation is that the changes in these factors (which are considered to be critical indicators of climate change) do cause a significant change in performance and
deterioration of pavements. To protect future generations from the burden of these expected detrimental changes, work is needed to improve pavement design and construction, to make pavements more resistant to the effects of climate change.

However, with rising costs and dwindling budgets, resources that are needed for such improvements are scarce. The proper way to tackle this situation is to optimize pavement performance against the expected changes, and to do so, one needs accurate and reliable data about climate changes, especially changes that will have significant effects on pavement performance. Although significant improvements in pavement design (both mix and structural) and construction (rehabilitation and maintenance) have taken place in recent years, there is a big gap in understanding climate change and its effects on pavement performance. For sustainable development, this information must be obtained through more collaborative research between climatologists and pavement engineers. In addition, available climate, pavement, and economic (as well as environmental) data must be integrated in system dynamics models and used for long-term predictions. Such modeling and simulation will be crucial for investigating the individual and combined effects of multiple factors (which are not from the same discipline) and identifying the more critical ones. Furthermore, once the critical factors are determined, critical levels of these factors, which can trigger nonlinear response of the key outputs, such as pavement life and costs of maintenance, can be identified. Unless a holistic evaluation is made with system dynamics, it will not be possible to optimize available resources to design and construct sustainable pavements.

CONCLUSIONS AND RECOMMENDATIONS

From this study, the following conclusions can be made:

1. System dynamics provide a practical way of evaluating the long-term effect of climate change on pavement performance.
2. A framework of using system dynamics to integrate climate change, pavement performance, and economics of pavement maintenance has been proposed.
3. Preliminary modeling and simulation show that the long-term effects of changes in air temperature, rainfall, seawater-level rise, and number of Category 3 hurricanes on pavement performance are significant.
4. For the expected changes in climatic conditions, a significant reduction in stiffness properties of both subgrade and HMA can be expected.
5. As a result of reduction in stiffness of the pavement layers, faster deterioration and a drastic reduction in the average life of pavements are expected.
6. As evident from the evaluation of increase in cost of maintenance as a result of climate change, costs are expected to increase significantly (>160% in 100 years) and nonlinearly.
7. The significant and early increase in cost is not apparent from predictions that do not take climate changes and their effects on pavement performance into consideration.

The work that is reported in this study clearly points out the necessity of the following recommendations:

1. Obtain more accurate and reliable data about relevant climate change factors; these data should be specific to regions, particularly those that are expected to be more vulnerable, such as coastal regions.
2. Use system dynamics to integrate the multidisciplinary topics of climate change, pavement design and performance, and economics into comprehensive studies.
3. Develop better models and refine the accuracy of predictions.
4. Conduct region- or site-specific modeling and simulations for accurate prediction of the impacts of climate change on pavement performance, transportation networks, and associated economic factors.

These recommended actions will allow researchers to have a clear idea about future needs, prepare research plans for developing appropriate materials and methods, identify vulnerable areas, plan properly for appropriate budget allocations, and optimize the expenditure of tax dollars.

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