SEISMIC VULNERABILITY OF PEREIRA CITY, COLOMBIA

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SUMMARY

The computer simulation of seismic events has an important roll in the estimation of potential losses, which is basic to support the decisions making in all fields: emergency management, urban planning, vulnerability reduction, definition of design standards, etc. But most important yet is the use of multiple damage scenarios, in which the simulation process is repeated for all probable events, allowing to establish the probability of exceeding losses and the correlations among them, fundamental base for the decisions making, the establishment of priorities and a financial handling of the risk.

The PERCAL and GRAPER programs allow to calculate scenarios of economic and life losses due to seismic events, keeping in mind a great quantity of variables from which, it is believed, depend the probable resistances of the structures, or the characteristics of the seismic movement that finally affects the structure. Then are considered, the amplitudes and frequency characteristics of the seismic event at bedrock, and the dynamic properties of the soil deposits on site in order to define the seismic excitation reaching the structures, and variables such as the socio-economical level, the number of floors, the roofing type, age and use of the building to define, based on these, the probable resistances to the seismic movement.

In this paper, the scenarios of two historical events are considered in order to calibrate the computer model, based on the data compiled from the infrastructure of the city of Pereira, and the evaluation of the damages caused by the earthquakes occurred on February 8, 1995 and on January 25, 1999.

INTRODUCTION

In the intensive urbanization process that Colombia has going through during the last decades, like in other Latin American nations, the concentration of the population phenomenon in a few urban centers has also occurred especially in the Colombian Andean zone. Pereira, as intermediate city, is an important populated center rated nowadays -in demographic terms - as the eighth city of the country with an estimated urban population of three hundred ninety thousand (390,000) inhabitants.

The lack of planning and the high dynamics of growth has caused a greater exposition of the population to the natural threats and has brought with it urban processes that increase its earthquake vulnerability. This is evident with the appearance of subnormal developments in areas inclined to the action of phenomena induced by the earthquakes (i.e. slides), with the canalization and non technical fillings of streams, with the construction of houses without appropriate antiseismic specifications, among other factors.

Since 1995 the Seismic Risk Mitigation Project is being developed in Pereira, with the purpose of identifying and analyzing the set of variables related to the seismic phenomenon and their consequences, to minimize the human, social and economic losses, by establishing planning and improvement policies of programs for the reduction of seismic risk and for attending emergencies. This project has a wide support and backing of the local

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and regional entities such as the Autonomous Regional Corporation of Risaralda -entity in charge of the environment at the State level-, the Government of Risaralda, the City Halls, the Pereira Public Services, and at national level, the Ministry of Environment, the National Institute of Research in Geoscience, Mining and Chemistry -INGEOMINAS – and the National Fund of Calamities.

Although the Seismic Risk Mitigation Project is still being developed, next are presented the advances that until now have been resulted from the valuation of the seismic vulnerability for a pilot sector of the city of Pereira formed by 700 blocks, what is considered approximately the third part of the city. Besides, the calibration of a computer simulator of seismic scenarios of losses is presented (PERCAL and GRAPER programs), by estimating the material and human losses that could be presented by an earthquake of similar characteristics to those occurred on February 8, 1995 and January 25, 1999.

DESCRIPTION OF THE CITY

Geographically, Pereira is located in a small valley formed near the edge of the western foothills of the Central Mountain range (4°48´ N, 75°41´W), to an average height of 1400m above sea level. The city has expanded quickly in the last decades, reaching an approximate area of 30 square km.

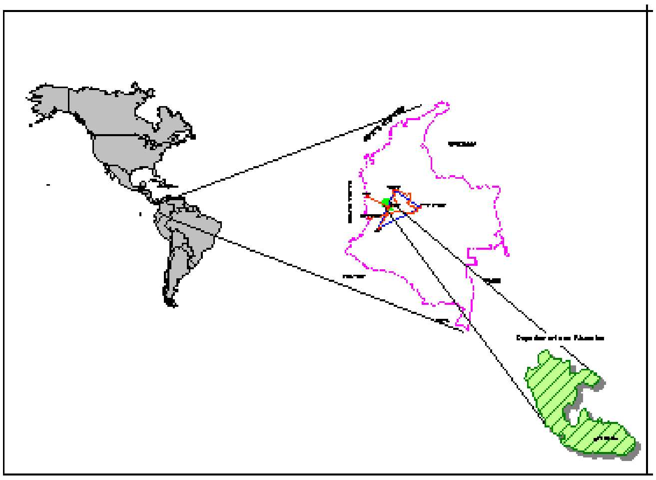

Figure 1: Localization of the city of Pereira

The current urban area possesses to special configuration given the topography which is characterized by the presence of hills lengthened in the East-West direction, separated by deep depressions, what made possible the practices of cut and fill. During the urban development of the area, the formation of non technical fillings has been a constant behavior as a system for construction debris disposal, for surpluses of earth movements or garbage, and as a land adaptation method for the construction of housing. Except for the fill zones, the areas subject to inundation and high slopes which form approximately 40% of the city deposits, the ashes coming from the volcanic complex Ruiz-Tolima cover the entire Pereira area.

The city of Pereira is characterized for having three predominant types of constructions: bahareque, brick masonry and reinforced concrete frames, which have evolved through time. The first houses during the foundation time (1863), were made of guadua - a kind of bamboo - with straw roof; subsequently, the houses were made of bahareque constructions (walls made with guadua structures and guadua plates, plastered with a blend of earth and vegetable fibers) with clay tile roof. The bahareque technique was used for many years for constructions of 1 and 2 floors, and rarely in three floor buildings.

In the city prevail the masonry construction of one or two floors, single-family type and small area; their characteristics differ depending upon the neighborhood. The majority could be classified as partial reinforced and unreinforced masonry dwellings. The reinforced concrete buildings that overcame the five floors represent less than 15 % of the total amount of constructions (See figure 2).

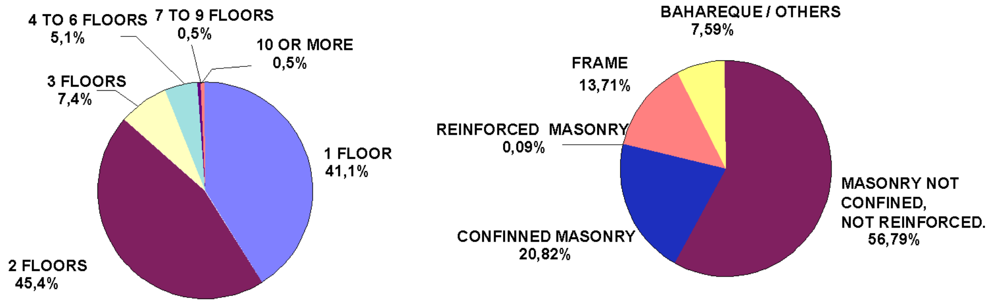

Figure 2: Distribution of buildings

DESCRIPTION OF DAMAGES IN THE FEBRUARY 8TH, 1995 EARTHQUAKE

The earthquake of February 8, 1995 was registered at 1:40 pm local time, had a magnitude 6.4 and its epicenter was located in the Calima-Darien region, boundary line of the departments of Valle and Chocó, to a depth of 75 km and to an epicentral distance of 120 km from the city of Pereira.

Pereira was the most affected city by this seismic event, whose epicentral distance is almost twice the distance to the city of Cali, where no damages were reported; although the trajectory and the source radiation patterns are unknown and assuming that the average quality of the construction is the same, this phenomenon indicates that Pereira has some areas that amplify the movement intensity in a severe manner. The closest accelerograph, located in Sevilla, 60 km away from Pereira, registered an acceleration of 0.04 g.

Some hours after the seismic movement, the local emergency entities developed a format for the inspection of the damages and to determine the possible use of the constructions. 1759 formats were carried out with the help of local engineers and architects.

According to the type of damage, the inspected buildings presented the following distribution: 3.59% suffered total collapse or had to be demolished subsequently, only two five-floor buildings collapsed by direct effect of the earthquake: 50.14% had repairable structural damages, 34.84% suffered non structural damages, and 11.43% suffered minor architectural damages. In total it is estimated that in the pilot sector the direct losses amounted to 42’119.143 dollars.

DESCRIPTION OF THE DAMAGES IN THE JANUARY 25TH, 1999 EARTHQUAKE

The earthquake of January 25, 1999, occurred at 1:19 P.M. local time, and was located near the town of Córdoba (Quindío), situated 48 km. to the south of the city of Pereira. The epicenter was calculated by the National Seismological Network as latitude of 4.30 degrees North, longitude of 75.64 degrees West and a depth less than 20 km. The magnitude Ml was 6.2.

The accelerograph network of the Seismic Risk Mitigation Project of Pereira, Dosquebradas and Santa Rosa de Cabal, registered the earthquake in 5 stations. The registered maximum acceleration corresponded to the station located on a non technical fill, with a value near to 0.30 g (290 cm/seg2) while the station located on the bedrock, indicated a value of 0.08 g (77.7 cm/seg2). In the other stations the maximum accelerations were in a range between 0.18 g and 0.25 g.

By comparing the acceleration registered on rock with those registered in softer materials, the amplifications factors were between 2 and 5.8 times. The fundamental periods of the soil vibration, in most of the stations were in a range between 0.6 and 0.8 seconds.

An inventory of the damages was accomplished classifying the buildings by colors depending upon the affectation degree and the possible danger to their inhabitants, the neighboring buildings and for the circulation of pedestrians or vehicles. More than 10.000 buildings were affected, of which 2,136 were located in the pilot sector. Next the distribution of damages is presented in accordance with the level of affectation and the number of floors:

Table 1: Distribution of damages caused by the 1999 earthquake

FLOORS	Demolished		Severe		Moderate		Ligth		TOTAL	%
	#	%	#	%	#	%	#	%		
1	43	22.01	94	22.01	239	29.80	179	23.99	555	25.98
2 to 3	90	56.21	240	56.21	399	49.75	372	49.87	1101	51.54
4 to 6	27	19.67	86	20.14	135	16.83	138	18.49	386	18.07
7 to 9	1	1.64	5	1.17	15	1.87	21	2.81	42	1.97
>10	0	0.47	2	0.47	14	1.75	36	4.83	52	2.43
TOTAL	161	100	427	100	802	100	746	100	2136	100
%		7.54		19.99		37.55		34.93	100	

MODELLING

By using the PERCAL and GRAPER programs the pilot sector of the city of Pereira was modeled in order to reproduce the damages and losses caused by the 1995 and 1999 earthquakes, and, based in this measuring, try to estimate scenarios of losses and damages that might take place in future earthquakes. Following are numbered the variables or parameters used by the PERCAL program to estimate the earthquakes losses; to each variable a value has been assigned as a result of the combination of a previous knowledge, product of the theory, of laboratory tests or of a field sampling and of a trial and error mechanism to reproduce what happened in the pilot sector during the two earthquakes. The PERCAL program receives the information through three files: the general data file, the sector or block file and the soil file.

The general data file includes information about the earthquake which is defined in terms of acceleration or magnitude and local attenuation functions, the parameters to calculate the Fourier and response spectra, the resistance of the buildings, its vulnerability and damages functions, the population densities and the construction value per square meter and the fraction of the cost of the structural elements. Also are included the correlation matrices indicating the way the probable combinations of the different variables should be made.

Each sector or block is characterized in terms of its area, location of its centroid, soil profile type and percentual distribution of the buildings in function of the structural type, roofing type, use, number of floors, socio-economical level and age of the buildings.

The soil types are defined indicating directly the transfer function of the soil or assigning a profile where the different strata are numbered with its thickness, density, S wave velocity and equivalent viscous damping in percentage of the critic, so that with this information the soil transfer function be calculated which modifies the Fourier amplitude spectrum of the movement in hard ground.

The program calculates the acceleration response spectra in each sector to be used as a measurement of the solicitations to which the structures will be subjected, and based in these and in the building resistances estimate the possible damages and losses presented. But the damages are not only related to the relationship between the solicitation and the resistance in terms of force, but rather, in the case of non structural elements, the damages are related to the relationship among the relative displacements (drifts) imposed on the structures and those the structures can resist.

Once calculated the fraction of the structural and non structural elements loss, the total value of the losses is calculated as the product of the cost of the structural elements times the fraction of the losses of these elements, plus the cost of the non structural elements times the fraction of the equivalent losses.

The calculation of human losses is based in the index of damages and the population density for square meter in function of the use and socio-economical level of the building, which allows to simulate the effects of the occurrence of an event to different hours.

COMPARISON OF THE REAL AND SIMULATION DAMAGES

It is presented below the results obtained from the calculation of the losses starting from the data bases of the post-seismic valuations and they are compared with the estimated cost of the existent infrastructure in the pilot sector. In addition the outputs of the simulation with the PERCAL program are presented.

Table 2: -Comparison of the value of the existent infrastructure with the real and simulated losses of the 95 and 99 earthquakes

Use	Total cost of Existing Buildings		Real losses 1995			Simulated 1995		Real losses 1999			Simulated 1999	
	U.S $	%	U.S $	%	R/E*	U.S $	%	U.S $	%	R/E*	U.S $	%
Residential	1,850,814,788	89.18	33,865,009	80.40	1.83	33,250,000	93.48	106,881,702	80.71	5.78	122,560,000	92.74
Commercial	182,317,622	8.79	7,581,670	18.00	4.16	1,821,230	5.12	23,916,228	18.06	13.12	7,754,400	5.87
Industrial	20,870,706	1.01	137.469	0.33	0.66	158.900	0.45	309.816	0.23	1.48	591.229	0.45
Educational	21,292,048	1.03	534.995	1.27	2.51	340.200	0.96	1,317,110	0.99	6.19	1,253,680	0.95
TOTAL	2,075,295,164	100	42,119,143	100		35,570,330	100	132,424,856	100		132,159,309	100

Number of Floors	Total cost of Existing Buildings		Real losses 1995			Simulated 1995		Real losses 1999			Simulated 1999	
	U.S $	%	U.S $	%	R/E *	U.S $	%	U.S $	%	R/E *	U.S $	%
1	259,960,460	12.53	1,112,360	2.64	0.43	509,600	1.43	6,303,744	4.76	2.42	3,489,000	2.64
2 at 3	1,119,771,186	53.96	7,450,120	17.69	0.67	11,600,000	32.62	33,748,252	25.48	3.01	58,428,429	44.21
4 at 6	388,408,168	18.72	11,096,966	26.35	2.86	5,266,110	14.81	45,324,235	34.23	11.67	23,660,000	17.90
7 at 9	134,160,787	6.46	7,254,072	17.22	5.41	7,382,000	20.76	17,890,194	13.51	13.33	19,867,000	15.03
>10 more	172,994,558	8.34	15,205,626	36.10	8.79	10,808,000	30.39	29,158,431	22.02	16.86	26,726,000	20.22
TOTAL	2,075,295,159	100	42,119,143	100		35,565,710	100	132,424,856	100		132,170,429	100

Socio-Economical Level -	Total cost of Existing Buildings		Real losses 1995			Simulated 1995		Real losses 1999			Simulated 1999	
	U.S $	%	U.S $	%	R/E	U.S $	%	U.S $	%	R/E *	U.S $	%
Low-Low (1)	12,223,959	0.59	87,932	0.21	0.72	246,800	0.69	211,390	0.16	1.73	791,300	0.60
Low (2)	53,481,603	2.58	112,643	0.27	0.21	363,600	1.02	601,475	0.45	1.12	2,206,000	1.67
Med. Low (3)	218,179,407	10.51	3,436,172	8.16	1.57	2,724,856	7.67	7,774,170	5.87	3.56	12,709,200	9.62
Medium (4)	477,946,118	23.03	9,219,227	21.89	1.93	6,804,400	19.15	30,521,711	23.05	6.39	30,255,000	22.89
Med. High (5)	825,524,403	39.78	17,151,370	40.72	2.08	10,633,000	29.92	68,106,430	51.43	8.25	45,420,000	34.36
High (6)	487,939,679	23.51	12,111,800	28.76	2.48	14,761,000	41.54	25,209,680	19.04	5.17	40,790,000	30.86
TOTAL	2,075,295,169	100	42,119,143	100		35,533,656	100	132,424,856	100		132,171,500	100

R/E * :Relationship between the value of the existing infrastructure and the real losses for each earthquake respectively (in all the tables).

ANALYSIS OF REAL DAMAGES PRODUCED BY THE EARTHQUAKES

The form of presentation of the results allows to observe the distribution for categories of the total cost of existing buildings, as well as the distribution of the real losses. Whenever categories are observed with very high values of losses and low values of existing infrastructure, it means a very high degree of vulnerability of that category of structures. Likewise, the presence of a distribution of losses opposed to the previous, it will mean a low degree of vulnerability of that category of structures.

The distribution of the losses for the socio-economical level, shows a concentration of the damages in the buildings of medium high (5) level, but it is also true that in the Pilot sector there is a great quantity of infrastructure in this level, which does not allow to conclude the existence of a high vulnerability for this type of buildings.

For the number of levels, a high concentration of losses in buildings of four to six floors is visible, nevertheless the percentage of infrastructure of this type of buildings is not too high. This fact does clearly mak a high vulnerability of this type of buildings in the Pilot Sector. Undoubtedly that this high vulnerability is due fundamentally to the effect of the local soils and to the predominant periods of the earthquakes; the natural frequencies of vibration of the soils coincide with the natural frequencies of vibration of that particular class of buildings. Besides, it is notable the low vulnerability of the buildings of two to three floors in the Pilot Sector; nevertheless be the type of construction most common in the sector, the presented losses are not too high.

The distribution of the losses by the use of the buildings, only marks the existence of a little higher vulnerability in constructions of educational and commercial use, than in residential use.

ANALYSIS OF THE SIMULATION RESULTS

In applying the PERCAL program to the pilot sector of the city of Pereira, it could be concluded that the results of the simulation are quite good in relation to the cost of the total losses; as a result of the formats the total losses in the Pilot Sector for the earthquake of 1995 amount to $42'119.143 US dollars and the simulation appraises losses for $35'565.710 US dollars, and for the earthquake of 1999 the losses amount to $132'424.856 US dollars and the simulation appraises $132'170.429 US dollars. The best adjustment of the losses for variables is according to the use (See figure 3); for all uses the real and simulated coincide rather well with exception of the commercial which presents great differences. It is worthwhile to bring out the good approach of the results in the residential sector, which is the predominant use in any city.

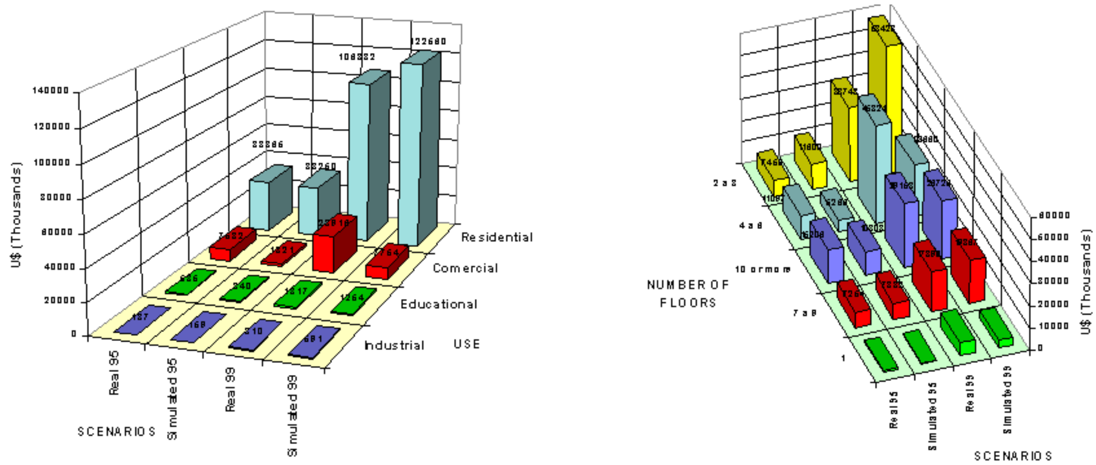

Figure 3: Real and simulated economical losses in the earthquakes of 1995 and 1999

Regarding the distribution of losses by the number of floors (See figure 3), it is where more inconsistencies are presented, because the differences in the simulated losses in relation with the real losses are very large. The losses in the simulation of the medium height buildings (4 to 6 floors) are underestimated in almost 50% and are over estimated in the houses of 1 and 2 floors. The problem could be either in a wrong assignment of the dynamic properties of the soil or in the model of transmission of waves used, and for the buildings of two to three floors probably the simulator is modeling with a lower resistance than the real one.

The simulation of the distribution of the losses according to the socio-economical level (Figure 4), although it is not very good in the adjustment of values, it is in the tendencies. The losses increase in the reality as much as in the model, until reaching the higher level where the losses are less than in the high medium level.

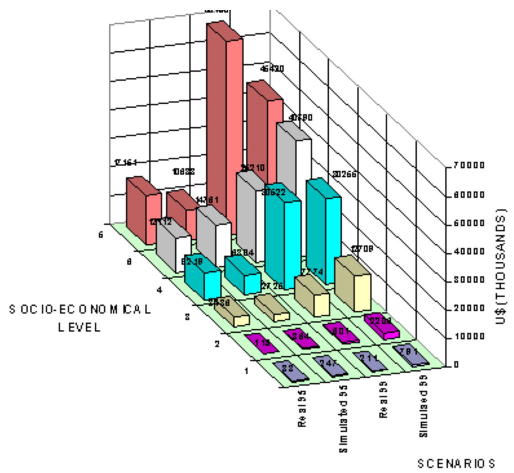

Figure 4: Real and simulated economical losses in the earthquakes of 1995 and 1999

CONCLUSIONS AND RECOMMENDATIONS

The problem in estimating losses scenarios for earthquakes is a problem rather complex; the elevated number of variables involved and the marked non linearity, make that the scheme presented to approach it, be quite appropriate. Foreign approaches, product of daring generalizations, could generate results very different from those that could be given in a specific location. Only with models that permit adjustments of their parameters based in real facts or scenarios, could expect predictions of more adjusted earthquakes losses.

The number of parameters used in the model could seem high, but for a first approach, when little or none sensibility about the importance of each of the variables is present, the most reliable scheme is that considering the greater possible amount of information both of experimental and empirical type, or still, subjective, although it is only qualitatively that may influence in the response. Finally, in a region which could be considered homogeneous in their techniques and constructive practices, and legislated by the same construction regulations, the variables and values controlling the problem could be known with a good precision level, and then, act in consequence over these parameters to reduce the seismic risk of the region. This is one of the main reasons to carry out vulnerability surveys of large urban areas.

Not only the disasters give us information about the variables ruling the problem. Many of the presented variables could be studied with a good approach making use of controlled experiments along with theoretical models about the behavior of materials and structural elements. In fact, many of the variables considered for the evaluation of the seismic risk of the city of Pereira are product of experimental and theoretical investigations on the behavior of materials and structural elements. It should be considered then that the laboratory and the theory as an important source of information to know the seismic response of the constructions and to refine the estimate of earthquake scenarios of losses.

The characteristics of the soil movement, and especially the response of deposits of soft soils or formations of stubborn geometry, must be analyzed in detail through a dense network of acceleration instruments. Only with a good amount of reliable records and quality in each of the geotechnical formations, it is possible to have the transfer functions of each soil type and diminish the uncertainties associated to the solicitations that really reach the structure, and, also the structure response, if instrumentation is provided in the structures. The above, would permit to replace the theoretical transfer functions, arising from a one-dimensional model of waves transmission considering the soil as a lineal elastic material with a mechanism of viscous damping in order to dissipate energy, for real transfer functions (empirical).

In relation with the application of the PERCAL program to the Pilot Sector of the city of Pereira, it could be concluded that the outputs of the simulation are quite good regarding the cost of the total losses with an approximation of 85% for the 95 earthquake and 98% for the 99 earthquake. The best adjustment of the losses per variables is according to use, followed for the socio-economical level, and presenting the major phase lag in the distribution per number of floors. In regard to the high vulnerability level of the two to three floor buildings forecast by the simulator, undoubtedly the problem is that this type of buildings resists much more than what is expected in the simulation, but this is the problem, to identify the appropriate parameters to accomplish simulation of the scenario of earthquake losses correctly. It will be followed to improve the calibrating of the model and its several variables, since the outputs presented in the following report are rather encouraging.

In the same way the distribution of the proportion of the losses per variables was presented, it could be studied the space distribution of the losses; in what sectors of the city could occur these losses, and discriminated per variables. For example, it is possible to see the scenario of losses in constructions of two to three floors, or in buildings of more than seven floors, or in buildings made with non reinforced, non confined masonry. These scenarios allow to identify problems of soil-structure interaction, allow to design plans of disasters attention, allow to design plans of land use, etc. The amount of possible scenarios is quite wide; the emerging needs and answers will take advantage of the collected information (data bases) and will be the tool to process it.

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