Renovating Cadastral Map- An Indian Perspective

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Key words: land administration, quality model, renovation, harmonization

SUMMARY

The poor implementation of land administration in India has resulted in lot of court cases (Ravi 2006), poor access to credit and delays in major infrastructure projects. (McKinsey 2001) suggests that if efficient land administration system in India can take care of the distortion in the land market, Indian GDP growth rates may go up by 1.3%. The Survey of India is embarking on a large-scale topographical mapping of the whole country and this provides a substantial opportunity to renovate the existing cadastral maps as done elsewhere in the world. The basic question is; how can it be done in India? In this paper, I have identified the various issues involved in it.

The literature survey reveals that the quality model based on relative precision, as practiced in Dutch cadastre is more meaningful to the users, and I have proposed the same for India. A simple methodology for tackling the difference in legal area and calculated area have been proposed, which gives the opportunity to fix this allowable difference by balancing the quality and required amount of fieldwork. It was realised that based on the prevailing situation and requirement two different approaches are available for the actual renovation of cadastral map. Having this in mind, a comprehensive framework comprising of both methods for the Indian cadastral system have been proposed. All the important processes involved in the renovation project have been modelled using UML activity diagram.

The paper concludes that existence of large-scale topographic map is a substantial opportunity and if India will successfully implement this project and improve its land administration, we may be in a position to corroborate the Mc Kinse prophesy of 1.3% increase in Indian GDP.

Renovating Cadastral Map- An Indian Perspective

Nirmalendu KUMAR, India

1. INTRODUCTION

The existing land administration system in India is a British legacy, and they had created it, with village as an administrative unit. The land administration is now the responsibility of state government and most of them have not carried out any revision survey and resettlement since independence. The existing land records in this paper based system is mostly outdated and do not reflect the ground realities about either ownership and possessions or boundary extent and classification. The quality of the cadastral map is not adequate to satisfy the today's customer needs (Rao 2000). The existence of large-scale topographical map at Survey of India (SOI) provides a substantial opportunity to renovate the existing cadastral maps as done elsewhere in the world.

The isolated paper maps are very difficult to maintain and keeping it up-to-date is not so easy. The most important cadastral activity is the cadastral updating process, which comprises of the daily revision of the cadastral information and map. The cartographic part of updating activity is very cumbersome in analogue format. The integration of analogue map with other existing geo-information for analysis and decision-making is also very difficult. On the other hand, the planner, administrator and common users increasingly require such integration. Improved quality of cadastral maps is also required in the context of Indian, National Spatial Data Infrastructure (NSDI) as cadastral data is a part of framework data.

The poor land administration in India has resulted in lot of court cases (Ravi 2006), poor access to credit and delays in major infrastructure projects. (McKinsey 2001) suggests that if efficient land administration system in India can take care of the distortion in the land market, Indian GDP growth rates may go up by 1.3%. In a fully digital environment a cost reduction and a personnel reduction of more than 50% is expected compared to the analogue approach (Osch 1995).

2. VARIOUS ISSUES INVOLVED IN MAP RENOVATION

The quality of the existing cadastral maps is very poor, which leads amongst others long litigations and inefficient land administration in India. This also makes the integration of cadastral data with other available geographic data very difficult, which is required in NSDI and by the users. Improving the quality of all existing cadastral maps in India is a gigantic task with various dimensions involved in it. It starts with; collection of what basic features/attributes (for the parcel) by SOI, while doing this large-scale topographical mapping may facilitates this process? Cadastral being the STATE subject in India (India has union, state and concurrent list for making legislation) what legislative changes/legal framework etc. are required to provide legal sanctity to those renovated maps? What capacity building like training, hardware, and software is required for this quality improvement process and what funding model may be appropriate for this huge project? What are the quality aspects of a cadastral map? What should be the actual process of this cadastral renovation? How one can manage the change in legal area and calculated area of the improved map for a parcel, and how the accuracy of renovated map can be reported? What can be the best projection system to facilitate a seamless cadastral map for the whole country? How to number uniquely the individual land parcels of the whole country so that to manage them in one database? How the new renovated maps can be published, and it can be made acceptable to various stakeholders? How to maintain this renovated map and archive the old cadastral map/keep historical stamp?

3. THE PROPOSED QUALITY MODEL

3.1 Quality

The term quality is generally used to indicate the superiority of a manufactured good or to attest a high degree of craftsmanship or artistry, but quality is more difficult to define (Nirmalendu 2003) for data, as they do not have physical characteristics. Quality in this case is generally understood as, a function of intangible properties such as accuracy, resolution, consistency, fitness of use and completeness.

3.2 Geospatial Data Quality Characteristics

Data quality issues have been extensively explored in the geographic information domain for about 20 years. However, definitions on the meaning of “quality” remain various. Two trends can be identified in the literature. One restricts quality to dataset internal characteristics, i.e., intrinsic properties resulting from data production methods (e.g., data acquisition technologies, data model, and storage). The other trend follows the “fitness for use” definition (Juran 1974), quality being defined as the level of fitness between data characteristics and user’s needs. As opposed to the former trend, the latter sees quality as a concept that is relative to the users and usages, neither an independent nor an absolute concept. Producer point of view generally focuses on internal quality, while user point of view looks at both internal and external quality.

3.3 The Data Quality Model

For a unified quality description of large scale mapping products, generally a model is developed for the geometric quality of pointfields, as a standardized description of geometric quality is not readily available (see e.g.(Caspary 1993)). A point field is a set of points of which the coordinates are given in a certain coordinates system, for example digital maps or databases with control points.

In this model, geometric quality has been described by means of more institutive and appealing concept of the relative precision of the points. One is not so much interested in the location of a point or object in the national reference system, but rather its location relative to nearby objects. In practice the use of geometric information deals with the relative position of the points. Therefore, it is logical to describe quality based on relative precision. Since the characteristic quantity of the model is relative precision, it is necessary that quality requirement be specified in terms of relative precision. In practice, most existing quality requirements regarding geometry can be translated into requirements based on the relative precision between points. More over as this model deals with cadastral map height is not taken as an element of the model description.

3.3.1 Acquisition precision and Identification precision

The relative precision of points in a point field is a function of acquisition precision and identification precision. The relative precision due to data capture and data processing is denoted as acquisition precision and is usually assigned to pointfields.
The precision with which a point can be pointed out in the terrain or in mathematical terms, the precision with which a point in the terrain can be modelled as a mathematical point is called identification precision and it is obvious that it depends on types of point. The corner of a building can be pointed out much more precisely than the middle of the ditch. Every point is assigned an identification precision.

Example

The concept of acquisition precision and identification is illustrated by figure-1 given below ,which is taken from (Martin Salzmann 1997).

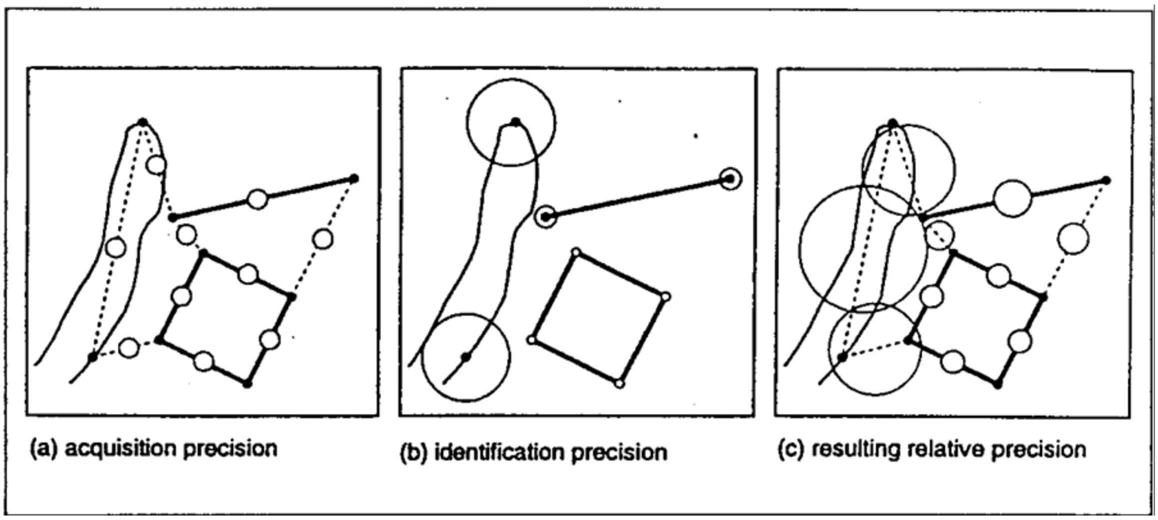

Figure 1: The relation between Acquisition precision, Identification precision and resulting precision

The precision is here represented by error ellipses (not to the scale) and acquisition precision is assumed distance independent, as a result, the relative error ellipses are of equal size between all points (a). In practice, such a result is expected after a photographic mapping. The precision of the identification varies from point to point depending on their characteristics; hence, in (b) the size of error ellipse in the corner of the building is much smaller than in the side of the ditch. Finally, the resulting relative precision between points is a function of both as in (c). From this example, it is clear that the relative precision between two points, which can be well identified, is mainly influenced by the acquisition precision, whereas the relative precision between two less well-defined points is mainly a function of the identification precision.

3.3.2 Implementation of quality model using variance-covariance matrices

For acquisition precision, actual covariance matrix of the coordinates as computed during data processing is not used because it is impractical as for an average map sheet it would contain thousand of elements. In stead, it is described by a limited no of parameters and if a point field has been created in a single production process, one set of parameters suffices to describe the relative precision between all points of that pointfield.
The identification precision is stored separately for every point but in practice, the pointfields are classified into different point types. In this model, three kinds of point fields are identified. Control points comprise points of the national triangulation network (including GPS points) and points of densification networks. It is assumed that they can be very precisely identified and the relative precision between two control points is a linear function of their mutual distance. Detail points include the points of the topographical and cadastral situation and constitute the bulk of the total number of points. For such points, the acquisition precision is modelled by means of a diagonal matrix (i.e. the relative precision between points is assumed constant). Local control points are easily recognizable detail points, which can be well identified and have to be selected carefully. They are very useful in the present quality improvement process as by using them; the relation ship between nearby objects can be maintained.
To accommodate the description of the geometric quality of the pointfields two types of artificial variance-covariance matrices are used.

Baarda-Alberda matrix: This matrix is based on a distance dependent covariance function between the points (Baarda 1973). This matrix has proven its usefulness for fields of control points and its structure is determined by the fact that the relative precision between the points is merely a linear function of the distance between the points. The relative error ellipse derived from this matrix is a circle.

The radius of this circle between two arbitrary points ‘ i ’ and ‘ j ’ is:

$$r = \sqrt{\sigma i^2 + \sigma j^2 + 2a + 2b\ell ij}$$

In this equation σi^2 and σj^2 are the variance related to the identification precision of points ‘ i ’ and ‘ j ’ respectively. The parameters ‘a’ and ‘b’ describe the linear covariance function of the acquisition precision. The quantity ‘ ℓij ’represents the distance between the points ‘ i ’and ‘ j ’. The parameter ‘a’ models the distance independent acquisition precision and the parameter ‘b’ models the distance dependence precision. For example for a general-purpose control network the identification precision of these points is negligible (i.e. zero) and the parameters are a= 0.0cm2 and b= 1.0 cm2/km.

Diagonal matrix: The diagonal matrix assumes no co-relation between coordinates of points and results in constant relative precision between all points in the point field and used for **detail points**. The relative error ellipse derived from this matrix is also a circle with radius

$$r = \sqrt{\sigma i^2 + \sigma j^2 + 2a}$$

The acquisition precision is now solely determined by parameter 'a', which can be assigned per point, pointfield and partial pointfield and thus the model cope with inhomogeneous point field.

3.3.3 Calculation of relative precision

In Dutch cadastre for built-up area the parameter 'a' = 400cm2 and in rural area 'a' = 1600 cm2 and each point is assigned a variance for the identification precision in accordance with its classification. Leaving the identification precision out of consideration these value corresponds to a relative precision between two points of 20√2 cm in built-up areas and 40√2 cm in rural areas (within one square km2).
The values of the parameter for the Indian cadastral map may also be found Following the same procedure.

4. HARMONIZATION OF LEGAL AREA AND RENOVATED PARCEL AREA

After the harmonization, the accuracy of a cadastral map will improve, but the boundary of the parcel will change during the process. This change in boundary will change the area of the parcel and the calculated area of a parcel before and after renovation will vary. But its legal area will remain same, as it is a legal identity. However, since the boundary on the ground will remain same this change in calculated area will not directly affect the owner of the parcel. **Therefore, it is suggested that there is no need to publish the new calculated area after renovation for the general public**, because once some one come to know that his parcel area has been reduced, he will have a fear psychosis that he will loose his land sooner than later. This will in fact open a Pandora box of another set of litigations for the already jam packed court. However, that does not mean that the difference in legal and calculated area will be left as it is without a quality control check. In fact, we have to put a limit on this variation compared to its legal area.

4.1 Quality Control Procedures for Harmonization

Quality always comes with associated cost, and hence if we want little variation in legal and newly calculated area requirement of consultation of field records and fieldwork will increase, which will require more resource on the part of the government. Considering this reality a methodology is proposed, which will provide options based on the concept of confidence limit. If X percentage confidence limit is Y square meter, it means X percentage of area will have a difference in legal and calculated area less than Y square meter. In this case, 98% confidence limit is proposed so that only for 2% cases, resolution of the differences is required. Harmonization of the differences will be first tried with the consultation of field records and if it is not possible to resolve it by that, fieldwork will be resorted to only as a last means.

Permissible difference in area, Tolerance can be expressed as a function of original area by means of a simple equation as suggested by (Lemmen 2003).

$$\textbf{Tolerance } (m^2) = q\sqrt{a}$$

Here ‘q’ is a constant and depend upon quality of the cadastral map. Area is represented by ‘a’ in m^2 . It is suggested that the constant ‘q’ may be calculated for three types of areas: rural, urban and for the centre of the city, for getting more closeness to reality. In Dutch cadastre value of ‘q’ for rural, urban and city centre are 1, 0.5, and 0.1 respectively.

4.2 Calculation of Q

The methodology given here will help to find the value of ‘q’ from original data set generated during renovation process. The appropriate sampling technique and sample size may be chosen as per the area under consideration. The value may be calculated in a simple table given below.

S no.	Parcel No.	Legal area of parcel in m2 A1	Calculated area of Parcel in m2 A2	|A1-A2| absolute difference d	$q = \frac{d}{\sqrt{A2}}$ in ‘m’
1 2 . .					

Table 1: Calculation of Q

Either now ‘q’ may be chosen by trial and error, based on confidence limit criteria or by percentage of cases needs to be investigated in field.

5. METHODOLOGY FOR IMPROVING THE QUALITY OF CADASTRAL MAP

5.1 Good Practices in Map Renovation

After analyzing the good practices around the world, it was found that for map renovation fieldwork has been avoided as far as possible, since it is very costly. In most of the cases, existing data was utilized for this quality improvement process and the new survey have been resorted to only, where it is ineluctable.

Two prominent approaches for renovating cadastral map are found. First, is by a reconciliation and harmonization process, using the other maps of higher accuracy of the same area and the second, is by using the available surveyor’s field records (distance, bearing and angle) and standard parametric least square adjustment and Constraint equations technique. The former approach has been taken in Dutch renovation process (Martin

Salzmann 1997; Martin Salzmann 1998; Osch 1995) and the latter by Australian (Masters 1999), Croatian (Rolae 1998), Slovenian (Triglav 1998).

5.2 Approach for Renovation of Indian Cadastral Maps

For the renovation of Indian cadastral map in most of the cases existing data may be utilized and new survey may be resorted to only, where it is ineluctable. In the areas where field records are not available but SOI topographical maps are available a methodology based on reconciliation, which is mainly based on Dutch renovation experience (Martin Salzmann 1997; Martin Salzmann 1998; Osch 1995) is being proposed.

For those areas, where the field data of the surveyor is available, (SOI map is not available) and situation warrants (e.g. urban fringe) for the improved quality of maps another methodology, as described by (Masters 1999; Michael Elfick 2005) may be adopted. For some areas where demands of accuracy by the user is not high the cadastral map may be digitized and provisionally transferred to national coordinate system in the first phase and quality improvement may be done later.

In India, the quality of the source material varies and in some cases, even they are unknown. This actually limits the possibility of advanced modelling for quality improvement process (Martin Salzmann 1997).

The proposed methodology may give the required accuracy, but if better accuracy than this is required by the user or otherwise, it can be achieved with additional connection points of higher accuracy using the same procedure, of course with additional cost.

5.3 Renovation Based on Reconciliation

This method may be used where field records are not available but SOI topographical maps are available. This methodology may be used in the majority of the area, and is described in more detail.

5.3.1 Creation of various scenarios

Since the whole quality improvement process consists of many steps, it is possible to create different scenarios based on the variables, availability of topographical map and format of cadastral map as shown in Table-2. The different scenarios will require different number of steps and this may help in efficient management of the project. A similar concept has been used in Dutch cadastre by (Osch 1995).

Topographical map / Cadastral map	Available	Not available
Analogue in Local coordinate system	C	D
Digital in Local coordinate system	B	A

Table 2: Table for creating different scenarios

Scenario	Steps required
A	Map boarder connection and provisional transformation
B	Cartographic map conversion and renovation
C	Digitization in addition to B
D	Digitization in addition to A

Table 3: Table showing scenarios and steps required

5.3.2 Various scenarios and procedures for their implementation

Scenario A

In this case, the cadastral department has already digitized the cadastral map and large-scale topographical map is not available for the quality improvement. In scenario A and D, normally quality improvement program may start when the topographical map is ready for that area. However, when there is a strong external demand by the user for digital cadastral map of that area a methodology for provisional conversion is suggested here so that cadastral map will be digitally available in national coordinate system. However, after this provisional conversion, required standard quality will not be achieved and in a later date, when topographical map will be available for the area it may be renovated as in scenario B except transformation in national coordinate system.

Procedure

1. Map border connection

The border of the adjacent two maps generally does not exactly fit hence; first step is to do cartographic connection between the two digitized map borders of the adjacent maps. The map boundaries of both the maps are then (semi-) automatically/manually corrected based on the scale of the two maps. If the scale of both of the maps is identical, average map border (smoothening) is required, otherwise boarder of the map of largest scale may be chosen. If the difference is larger, smooth the effect on adjacent parcel boundaries, and re-adjust the intersecting parcel boundaries with the new map border. Recalculate the parcel area (the software at this stage should automatically do it), which should not differ much (see section 4.1 for detail) from original value. If the difference in areas is, too much a limited correction of adjacent parcel boundaries is advised.

2. Provisional Transformation

Now these maps have to be transferred from local coordinate system to national coordinate system. For this select a suitable set of adjacent maps from topographical database and convert it to analogue cadastral scale, for better identification. Choose appropriate connection points or lines in the cadastral map border. If it is extremely necessary, some additional connection points at required locations may be measured with GPS in order to get a suitable set of transformation parameters. Now identify these chosen points in the digitized cadastral map, which now have two sets of coordinates (local and national). Prepare/Use an existing adjustment program, which connects all map borders to one local coordinate system and transform the resulting pointfield to the national coordinate system using the identified connection points/GPS points.

Scenario B

In this case, also, cadastral maps are available in digital format but in local coordinate system and Topographical map is available for quality improvement.

Procedure

Here also map border connection will be done first, as explained in scenario A. However, here the cadastral map will be converted to national co-ordinate system using topographical map as geometric reference. Since the topographical map contains enough objects, which are also available in cadastral map, well-defined, uniformly distributed connection points should be identified for the transformation. The quality improvement is done in five stages as described below. It is important to note here that conceptually these are the steps , which need to be done separately and operationally many steps may be combined in a software and can be done in one go. Similarly, it is prudent to have software, which do (semi-) automatically these steps to be less time consuming and cost effective.

1. Pre-processing and transformation

Since, here our cadastral map is in the local coordinate system and large scale topographical map is in the national coordinate system the improvement procedure will begin with a transformation, which is performed in an iterative process. The transformation helps in eliminating gross errors and in selecting homogeneous parts of the map. First a Helmert transformation (or a over-determined similarity transformation) is computed using a number of well defined corresponding point in the map or connection points to compute approximate transformation parameters. Using the results, additional connection points can be selected and it is always advantageous if it can be done (semi-) automatic.
Next one uses a Helmert transformation based on all connection points to eliminate gross errors and to obtain improved approximate values.

2. Connection adjustment

In some cases after the transformation, least squares connection adjustment is done for error detection and determination of the quality of the map. Especially in cases, where information on the quality of the map is missing, the test can give indication of the quality of the cadastral map. After the connection adjustment, the inconsistency in the connection points is removed. In this step one might also consider to use additional connection elements, for example line elements. The execution of this connection adjustment requires a reasonably well defined stochastic model of the connection points (or line).

3. Interpolation

After the transformation (and possibly adjustment), the coordinates of the connection points or elements of the cadastral map are corrected. The residuals in the connection points are interpolated in the map to maintain the homogeneity of the cadastral map. All points not being connection points, the so-called free points, are corrected and this correction should preferably be comparable with that of connection points nearby. In the Dutch cadastre for this interpolation a least square interpolation technique, which was originally developed for the interpolation of control network (Buiten 1982) was used, and the same may be used for Indian case also.

4. Reconciliation

Additional adjustment is performed to improve the local relationship within the map. It is the most time consuming activity in the map renovation process but it improves the quality of the map locally, in particular the geometric relations in the map is better warranted. It has to be decided boundary by boundary, whether it coincides with the topography depicted on the large-scale topographical map. For this step, interactive graphical tool is very handy and may be developed. The field sheet/sketch can be used here for interpretation purposes. For example based on surveyor field sketch one can decide, whether the middle of the ditch coincide with a cadastral boundary. A thumb rule that if the separation between the two is less than half of the acceptable relative precision then they made to coincide, can be used. The local adjustment is truly local and information in the nearby of the relations is only used. Here it is insured that connection points remain unchanged in local adjustment.

5. Post processing

This last step is very much concerned with the integrity and consistency of the geometric database. Checks on the quality, attribute accuracies, completeness and topologic consistency are being done after map renovation. Administrative database/registry database is also made consistent with the renovated map.

Scenario C and D

Scenario C is same as digitization in addition to B, and scenario D is same as digitization in addition to A. Scenario A and B has already been explained but cartographic digitization is briefly explained below.

Digitization of cadastral map

The manual input method and the screen digitization guarantee the high accuracy, but they are very time consuming and hence inapplicable for the digitization of cadastral map. In the automated vectorizing, a line-searching algorithm is generally utilized and the cadastral maps, which are in good state, can be digitized with this method. Incorrect location can be edited with editing operation on a computer screen. For the cadastral map , which are not in good state (which is generally the case) a hybrid vectorization, which uses the line thinning for minimizing the data for automatic recognition of pattern and automatic line searching algorithm based on intersection points of lines as used in Korea (Byoungjun SEO 2001) can be developed for digitization

5.4 Renovation based on Boundary Connection

This methodology is suitable for the area where field data is available and cadastral boundary database (CBDB) exist. This adjustment technique is based on standard parametric least square adjustment and formulation of Constraint equations for each data type or conditions (Masters 1999; Michael Elfick 2005). The basic assumption used in this process is the CBDB has its own inherent shape that should be preserved unless other higher accuracy information is available. Thus, the most fundamental data is the distances and directions between points in the database as defined by the line work. The Australian Cadastre used this technique for their upgrade process(Masters 1999).

The knowledge of boundary definition processes and their evolution can also be used in developing conditions, which can be used in upgrading process.

5.5 Methods for Adding Accurate Data

Classical method of entering the bearing and distance of each line around each parcel for each deposited plan may allow check to be made in data entry but nearly every line has to be entered twice , which makes it very time consuming and costly. This approach may be avoided and intrinsic value of CBDB may be used to 'hang' the bearing and distances on and then to use the CBDB topology to assist the validation process. In this way 90% of the data entry cost may be saved as firstly bearing and distances are entered only once and secondly use of GIS tools meant that many bearings and distances could be entered only once for many features e.g. along side and rear boundaries and road frontage (Masters 1999). Software routines may be developed to ensure that good data are going into adjustment process. For example if the parcel's bearings and distances closes, the arcs making up the parcel are passed and where it do not close each line is compared to the CBDB, which permits gross errors to be detected.

5.6 Activity Diagram for the whole Cadastral Renovation Process

Although all the processes involved in this map renovation project could not be described in this paper due to restriction in word limit. However, all the main steps of this map renovation process are being modelled using Unified Modelling Language (UML), activity diagram to give the complete picture. The diagram is self-explanatory and it has been shown as **figure -2.**

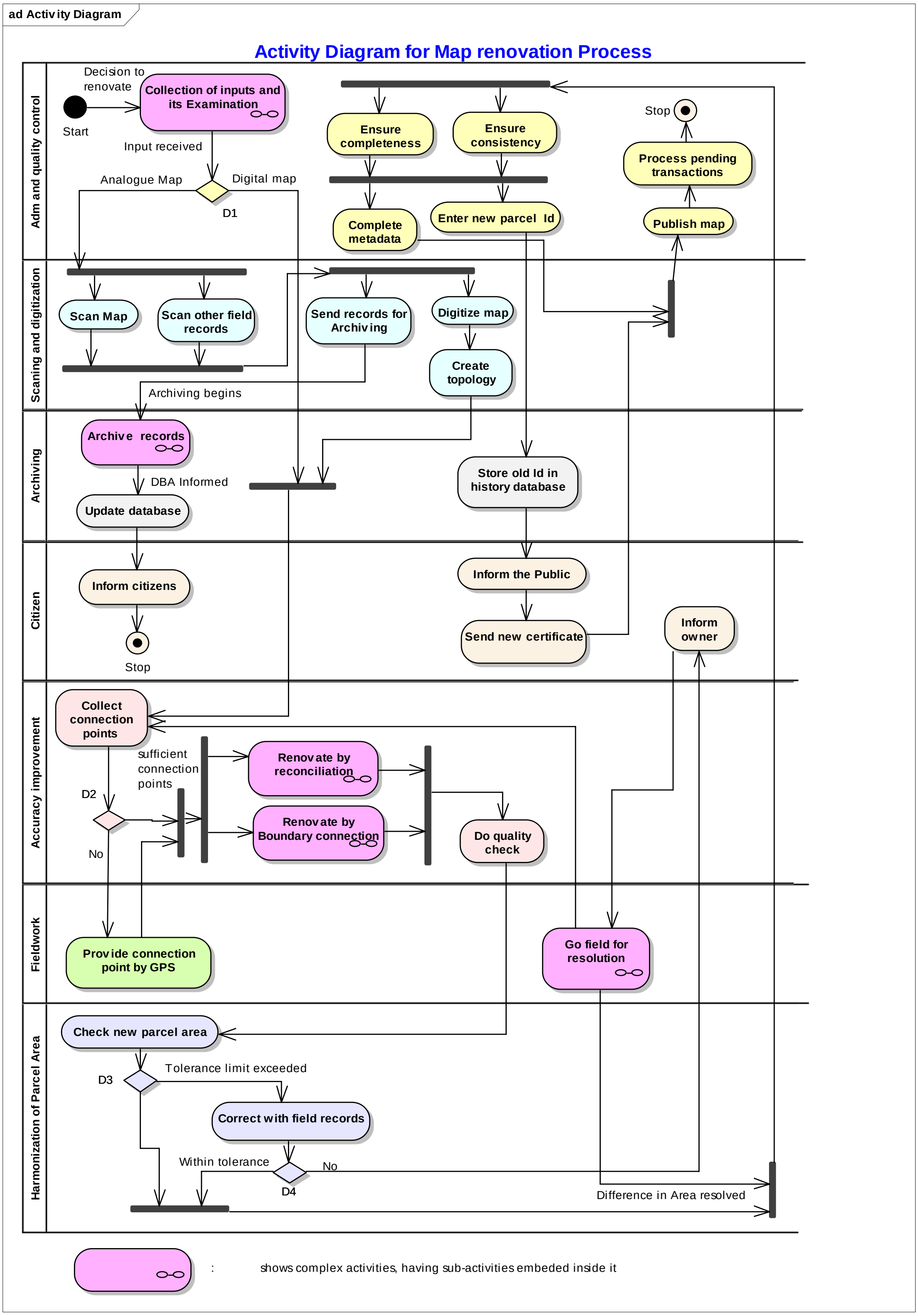

Figure 2: Activity diagram for the map renovation process

6 CONCLUSIONS

- The existence of large-scale topographical map at the Survey of India provides a substantial opportunity for the renovation of cadastral map in India and the framework presented in this report for map renovation is capable of meeting diverse quality improvement requirement of the vast country.
- The quality model proposed based on relative precision gives more meaning to the customers.
- The methodology purposed for tackling the difference in legal area and new calculated area will give opportunity to the manager of this project to seek balance between the quality and amount of fieldwork during its actual implementation.
- Only, the conceptual technical details for the map renovation have been worked out in this paper. Many new dimensions and complicacy not thought out in this paper has to be sort out, which may arise at the time of its actual implementation.
- If the cadastral renovation project is successfully implemented and land administration in India is improved (accessible, complete, accurate, up-to-date), we can realise its dormant potential and may be in a position to corroborate the Mc Kinsey prophesy of 1.3% increase in Indian GDP.

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BIOGRAPHICAL NOTES

He is an M. Tech. in Surveying Technology from JNTU, Hyderabad, India and joined National mapping organization, Survey of India in 1993, through IES conducted by UPSC. He has worked in various capacities for past 13 years in survey of India and has very wide fieldwork, photogrammetry, remote sensing and GIS experiences in the domain of surveying and mapping. He is a proud member of the 19th Indian scientific expedition to Antarctica in 1999. Recently he obtained his Master degree in ***Geo-information management*** from ITC, The Netherlands with distinction in 2006. He is an active member of the several professional bodies like, Institution of Engineers (India), Institution of surveyors, computer society of India, Indian society of remote sensing, Indian society of geomatics and Indian science congress association. He has presented several papers in international and national conferences like GSDI-9, Map India and INCA.

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