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Original article

Small Scale Map Projection and Coordinate System Improvement in Consideration of Usability and Compatibility

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Abstract

Small-scale maps currently used are made by scanning and editing printed maps and its shortcoming is accumulated errors at the time of editing and low accuracy. TM projection method is used but its accuracy varies. In addition, small-scale maps are made without consideration of usability and compatibility with other scale maps. Therefore, it is necessary to suggest projection and coordinates system improvement methods in consideration of usability and compatibility between data. The results of this study reveal that in order to make the optimum small-scale map, projection that fits the purpose of map usage in each scale, coordinate system and neat line composition should be selected in consideration of interrelation and compatibility with other maps. Conic projection should be used to accurately illustrate the entire country, but considering usability and compatibility with other maps, traversing cylindrical projection should be used instead of conic projection. For coordinates system of the small-scale map, Universal Transverse Mercator (UTM-K) based on the World Geodetic System should be used instead of conventional longitude and latitude coordinate system or Transverse Mercator.

Keywords : Small-Scale Map, Projection, Coordinate System, Neat Line Composition, UTM-K

1. Introduction

The purpose of this study is to suggest projection and coordinate system improvement methods in order to increase accuracy and usability of the small-scale map. To make an accurate small-scale map, this study presents enhancement methods of project and coordinate system conventionally in use, and a way to apply the optimum coordinate system in consideration of usability for users and compatibility between data.

In general, maps are classified by small-scale maps and large-scale maps based on 1/100,000 scale. Small-scale maps issued by NGII are 1/250,000-scale topographic map, 1/1,000,000-scale complete map of Korea, 1/3,000,000-scale adjacent map of Korea, 1/33,000,000-scale world map. Coordinate system currently used in small-scale maps uses TM projection and Transverse Mercator. According to the revision document in 2000, suggesting enhancement of small and medium-scale map projection, it is presented that 1/250,000-scale topographic map shall use TM projection and Lambert projection together, while 1/1,000,000-scale complete map of Korea shall use Lambert Projection. In 2012, projection and coordinate system was refined by small-scale map elegance promotion project. However, no discussion has been made on accurate projection and coordinate system of small-scale maps. Globally, the trend of converting into Transverse Mercator as the universal system has shown more clearly, but Transverse Mercator of the general map used for making the National Base Map and the thematic map is bi-furcated, making it difficult to control the national

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spatial information at the national-level, while deteriorating efficiency of exchange cost for inter-agency information sharing and usability in work.

In this regard, this study aims to research an enhancement method for the optimum coordinate system and projection to promote efficient building of small-scale maps and to increase its usability.

To present an enhancement method for the accurate and highly usable small-scale maps, an analysis is made on the projection and coordinate system used to make a similar–scale map to small-scale maps of Korea in the country with a similar topography to Korea or the country located at the similar latitude to Korea. Based on the analysis results, problems of the conventional small-scale maps are derived and the optimum method generated from enhancement of coordinate system projection and neat line composition is presented to increase accuracy and usability. To suggest an application method, accuracy per projection - cylindrical projection, conic projection or planar projection - is analyzed, and distortion quantity by Tissot's indicatrix in accordance with scale factor in the cylindrical projection is also analyzed to select projection and coordinate system appropriate for small-scale maps.

2. Small–Scale Map Coordinate System Status and Enhancement Method

2.1 Analysis of coordinate system in small–scale maps

To deduct problems of coordinate system and projection in small-scale maps, 1/250,000-scale topographic map and 1/million-scale complete map of Korea are investigated and analyzed for the status of coordinate system and projection currently used in the domestic small-scale maps issued by NGII.

At present, small-scale maps uses the World Geodetic System in accordance with regulations in Article 7 「Law Enforcement on Spatial Information Establishment and Management」, and Transverse Mercator for projection. NGII, in 2012, announced 「Small-Scale Map Diagram Application Regulations」 by refining projection and coordinate system through the small-scale map elegance promotion project, and Table 1 shows the defined coordinate system and projection of small-scale maps per scale.

Table 1. Small-scale map coordinate system standard (write in small characters)

Maps	Coordinate System
1/250,000 Topographic Map	Coordinate System: Transverse Mercator Projection: Traversing Mercator Added Value: X (N)=2,000,000m, Y (E)=1,000,000m Scale Factor: 0.9996
1/1,000,000 Complete Map of Korea	Coordinate System: Transverse Mercator Projection: Traversing Mercator Added Value: X (N)=2,000,000m, Y (E)=1,000,000m Scale Factor: 0.9600

In the case of the topographic map, the scale factor of 0.9996 is used for TM projection to allow output that fits the printing paper, but in such a case, a distortion may occur depending on scale factors. Due to limitation in the printing paper, a way to change the scale to 1/1,200,000 was studied for the complete map of Korea, but under the current regulation, the scale factor is changed to 0.9600 to create 1/1,000,000-scale complete map of Korea, which may generate distortion quantity. In addition, when Dokdo Island and Ieodo Island is included in the illustration range of the complete map of Korea, conic projection should be considered, instead of TM projection more appropriate for the shape stretching out south to north. Therefore, it is necessary to present the most appropriate projection and coordinate system for small-scale maps.

For overseas coordinate system of small-scale maps, the coordinate system and projection currently used in the US, UK, China, Japan, Germany, Australia, Europe and other major countries in the world are investigated and analyzed. Most of countries are using various kinds of coordinate system and map projection depending on the regional characteristics and the scale of the map.

Countries located at a similar latitude to Korea (located between 30 ~ 45° northern latitude) include Portugal, Spain, Italy, Greece, Turkey, Kazakhstan, Uzbekistan, China, Japan and the US. The area of the entire Korean peninsular including both South and North Korea is approximately

220,258 ㎢ and the UK has a similar area to the Korean peninsular with approximately 243,610 ㎢.

Projections used in European countries vary including TM, UTM and Lambert Conformal Conic, and each country uses a different scale factor depending on the projection used. In particular, countries using UTM takes 0.9996, the scale factor of UTM as it is.

2.2 Improvement of small-scale map projection and coordinate system

Coordinate system and projection of small-scale maps (1/250,000~1/3,000,000) currently used in the US, UK, China, Japan and other major countries in the world mostly take TM projection or UTM coordinate system, along with Lambert projection. In a country like Italy and Spain stretching out north to south that has a similar geographic shape to the Korean peninsular and is located at a similar northern latitude (38°), UTM coordinate system is used for small-scale maps.

When it comes to select the projection by the scale based on DMA, Technical Manual 8358.2, as show in Table 2, TM projection can be used to make the physical map in more than 1/500,000 scale, the hydrographic map in more than 1/50,000 scale and the aeronautical map in 1/250,000 scale, while Lambert conformal conic projection can be used to make the physical map in less than 1/1,000,000 scale and the aeronautical map in less than 1/500,000 scale.

Table 2. Projection application range per scale

Projection	Scale	Type
TM Projection	More than 1/500,000	Physical Map
	More than 1/50,000	Hydrographic Map
	1/250,000	Aeronautical map
Lambert Conformal Conic Projection	Less than 1/million	Physical Map
	Less than 1/500000	Aeronautical map

A specific projection can be applied to the map depending on its purpose and such a map includes the aeronautical map, marine map and statistical map.

Aeronautical map is TM projection or Lambert conformal conic projection, General map of Coast (Marine map) map is TM projection or Lambert conformal conic projection, Statistical Map is Various equal-area projections.

It is necessary to adjust and change the projection and scale factor for application in order to illustrate the entire Korea using the single origin point. Most of previous studies in the coordinate system focused on how to minimize distortion quantity and in most cases, accuracy was considered in 1/5000 medium-scale maps. However, in the case of 1/million complete map of Korea, the nature of definite form that allows immediate identification at a glance should be considered first instead of accuracy-based analysis.

Therefore, in selecting projection and coordinate system, considering better accuracy, compatibility, easy frequent editing and usability based on the purpose of small-scale maps, basic characteristics of projection and manufacturing status, it is recommended to use Universal Transverse Mercator (UTM-K), considering usability of the manufactured small-scale map and compatibility with other spatial information, instead of Transverse Mercator of TM projection, the projection and coordinate system for raw data used to make small-scale maps based on its accuracy and easiness to use.

It is recommended to use TM projection for the optimum projection for small-scale maps with uniformed added values. In the case of the complete map of Korea, considering the size of printing paper, it is necessary to change the scale and scale factor to include the Ieodo Ocean Research Station located at the southernmost of the country.

3. Accurate Evaluation of Projection

The most scientific method to evaluate accuracy of each projection is to use 'Tissot's indicatrix' developed by Nicholas Auguste Tissot, a French mathematician. In Tissot's indicatrix, as shown in Fig. 1 (Slocum *et al*., 2009), an infinitesimal unit circle is illustrated and projected around the point where the latitude and the longitude meets and distortions appeared on the circle are illustrated. That is, it visualizes the characteristic of projection through spatial distribution of distortions.

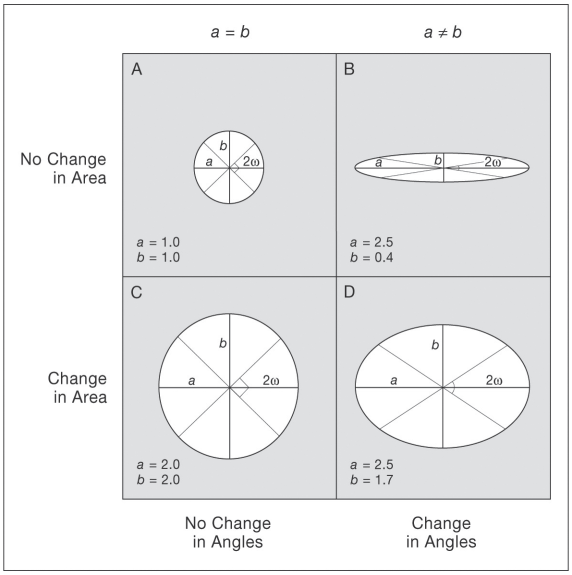


Fig. 1. Illustration of distortions by Tissot's indicatrix

According to Lee and Cho (2012), the projection distortion analysis is divided into the analysis of 'infinitesimal scale' and that of 'infinite scale'. The analysis of infinitesimal scale is based on Tissot's indicatrix, in which distortion trends appear in the infinitesimally small area, while the analysis of infinite scale illustrates substantive distortions actually generated on the map. The analysis of infinitesimal scale is mainly used because Tissot's indicatrix is the most-widely used conceptual tool for map distortions, and because it has a lot of advantages in terms of practicability with the widely known calculation formula for most of projection (Laskowski, 1989; Snyder, 1987; Bugayevskiy and Snyder, 1995).

In particular, when the local distortion is calculated for each projection by the map attribute, such as an angle (shape), area, and scale (distance), it is possible to view their spatial distribution or calculate distortions of the entire area, which allows relative comparison between different projections.

Canters states that distortions identifiable at the local level based on Tissot's indicatrix are three; angle, area and scale (Canters and Decleir, 1989; Canters, 2002). It is the most widely used method to analyze projections based on Tissot's indicatrix, a representative measurement tool of local distortions. All positions in the map under the designated projection have an indicatrix with a specific parameter. The most important parameter value is the scale factor of the major axis (a) and that of the minor axis (b) in the indicatrix. Using these two parameters, it is possible to find the local distortion index on angle, area and scale (Canters and Decleir, 1989).

$$2\omega = 2\arcsin\frac{a-b}{a+b} \tag{1}$$

$$\sigma = ab \tag{2}$$

$$(a-1)^2 + (b-1)^2 \tag{3}$$

Here, 2ω indicates the maximum angle distortion, and δ indicates the area distortion. Eq. (3) is the most widely used scale distortion index, and it is designed to consider the scale distortion of both directions of the major and minor axes (Canters and Decleir, 1989). If we make the isarithmic map by calculating such values in all points, we can effectively illustrate spatial distribution of distortions for angles and areas per projection methods. Laskowski (1997a, 1997b) defines such indexes in a slightly different method; he presents a/b -1 for the shape distortion index and ab-1 for the area distortion index, while maintaining the scale distortion index the same. However, the mentioned formula is altered when the parameter 'h' and the parameter 'k', representing the scale factor on the longitude line and that on the latitude line respectively, are given (Canters and Decleir, 1989; Čapek, 2001). It is essential to have a new formula when the longitude line and the latitude line in projection do not orthogonally come across.

$$2\omega = 2\arctan\frac{1}{2}\sqrt{\frac{h^2+k^2}{hksin\theta'}-2} \tag{4}$$

$$\sigma = hksin\theta' \tag{5}$$

Here, θ′ indicates the angle generated by meeting of the longitude line and the latitude line. If we add such local distortions throughout the entire map in a specific method, we can calculate the global distortion. In this case, we can only calculate the global distortion for some areas of the map. Based on such a discussion, presented three kinds of the global distortion index; they are 'mean angular deformation, D_{an}', 'weighted mean error in areal distortion, D_{ar}', and 'weighted mean error in the overall scale distortion, D_{ab}' and the following indicates the formula (Canters and Decleir, 1989; Canters, 2002).

$$D_{an} = \frac{1}{S}\sum_{j}^{m} 2\arcsin\left(\frac{a_j - b_j}{a_j + b_j}\right)\cos\phi_j \Delta\phi\Delta\lambda \quad (6)$$

$$D_{ar} = \frac{1}{S}\sum_{j}^{m} \left[(a_j b_j)^p - 1\right]\cos\phi_j \Delta\phi\Delta\lambda \quad (7)$$

$$D_{ab} = \frac{1}{S}\sum_{j}^{m} \left(\frac{a_j^q + b_j^r}{2} - 1\right)\cos\phi_j \Delta\phi\Delta\lambda \quad (8)$$

Here, p, q, r is binominal parameter, and the detailed definition refers to Canters and Decleir (1989). S indicates the overall map area (area). If we do integral calculus on the distortion calculated by m-number of grid point and find out its average, we can figure out the global distortion for each element, which brings the following formula (Canters and Decleir, 1989).

$$S = \sum_{j=1}^{m} \cos\phi_j \Delta\phi\Delta\lambda \quad (9)$$

Here, $\Delta\varphi$ indicates the distance on the latitude between grid points, while $\Delta\lambda$ indicates the distance on the longitude between grid points. Paying attention to the fact that the focus of distortion does not concentrate on the entire globe but on the land area, Canters additionally defines the distortion index, calculated only for the land area; D_{anc}, D_{arc}, D_{abc}(Canters and Decleir, 1989; Canters, 2002). 6 global distortion indexes were calculated for the total of 54 projection methods appropriate to use to make the global map. For example, the weighted mean error in areal distortion (D_{arc}) in Robinson projection and Winkel Tripel projection is 0.21 and 0.17, respectively and the latter is lower. However, D_{ar} that only considers the land area show the same value of 0.25 for both projections. Čapek (2001) called such a method 'global mean distortion calculation method' in a sense that the global distortion is calculated by taking the mean value of local distortion in each element. This method was created as an attempt to calculate the overall distortion of the projection by combining the global distortion of each element.

Canters (2002), instead of applying a specific calculation to the previously mentioned three global distortion indexes, believed that the scale distortion index can be used as the overall distortion index because the scale distortion is involved in both the angle distortion and the area distortion. Goldberg and Gott III (*2007*) developed a new indicatrix by altering Tissot's indicatrix, suggesting an additional local distortion index for 'flexion' and 'skewness'. They estimated the global distortion of the total of 6 distortions and figured out the overall distortion value by their sum of squares, although it is an analysis of the finite scale.

Canters's study shows the typical method of estimating the global mean distortion. The final combined distortion is calculated by standardizing the global shape distortion and the area distortion and then adding the values. Instead of using such a calculation to figure out the global mean distortion, Čapek (2001) suggested an approach called 'Outlier Criteria', which is a method to calculate the area ratio of the zone that both area and angle do not exceed the maximum acceptance distortion (Canters *et al*., 2005). Based on the local area distortion on areas and angles, Čapek (2001) devised 'Distortion Characterization Q', a global-level distortion index. This index indicates the area weight of the zone that satisfies both the maximum acceptance distortion of the angle (40°) and the maximum acceptance distortion of the area (1.5 times to the minimum area distortion). Jenny *et al*. (2008) called it AI (Acceptance Index) and included it into Flex Project Software that they made.

In illustrating distortions by the scale factor, SF (scale factor) indicates the value generated by dividing the scale of the planar map by the scale of the globe, and the following is the formula.

$$SF = \frac{actual\ RF}{principle\ RF} \quad (10)$$

Here, RF (reference fraction) is the principle scale, simply representing a fraction or a ratio. For example, if the scale factor (SF) is 2.0, it means that the actual scale is twice as much as the reference scale on the globe.

SF in the large-scale map slightly alters around 1 depending on the position. For example, for the longitude 6° zone in the large-scale map using UTM projection, SF alters from 0.99960 to 1.00158.

When illustrating the distortion generated by such scale factor (SF), the standard line is the reference line of map projections. The longitude line (meridian), the latitude line or the equator is used for the standard line and no distortion is generated along the standard line. That is, a=b, S=1.0, $2\omega=0^{\circ}$. However, in other points that the reference line, Scale Factor changes.

4. Application and Analysis

4.1 Selection and analysis of application subject

To suggest a method of making accurate and highly usable small-scale maps, this study deduces problems of the conventionally used coordinate system and projections and suggests the optimum projection and enhancement method of coordinate system. In order to analyze accuracy by projection methods, cylindrical projection, planar projection, conic projection and compromise projection methods were compared and analyzed for 1/250,000 topographic map and 1/million complete map of Korea, and accuracy and pros/cons of Lambert conic projection and traversing cylindrical projection, used the most in domestic and overseas small-scale maps, are compared and analyzed. For neat line composition in small-scale maps, the neat line composition by longitude/latitude and that on transverse Mercator are compared and analyzed. Fig. 2 shows the national boundary to analyze accuracy of projections.

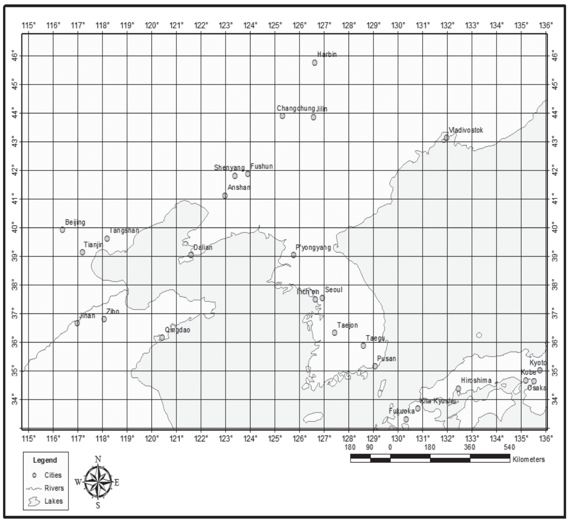


Fig. 2. Study area

When it comes to coordinate system and projections currently used in small-scale maps, the projection and coordinate system is not illustrated due to unclearness of map making. However, it is expected that Traversing Mercator and UTM-K (Universal Transverse Mercator) be used, considering interviews with mapmakers and shapes of maps. Therefore, in this study, in order to analyze accuracy in individual projections and coordinate systems, the conventional coordinate system is set to UTM-K and the accuracy generated by Lambert projection (conic projection) and by TM projection (traversing cylindrical projection) are compared and analyzed.

4.2 Accuracy by projection and coordinate system

4.2.1 Scale factor by projections

To analyze accuracy by projections, cylindrical projection, planar projection, conic projection and compromise projections are used to project the application subject.

As shown in Fig. 3, in the cylindrical projection, the cylindrical surface touches the ellipsoid surface for projection. In this case, no distortion is generated on the central meridian that the cylinder touches the earth ellipsoid, but more distortion is found further away from the central meridian. Therefore, this projection is appropriate for regions stretching out north to south as in the case of Korea, but on the other hand, it generates distortion around projection axis and in area.

Planar projection, as shown in Fig. 4, generates distortions under accurate azimuth. It is symmetric based on projection center but distortion is generated further away from the projection center. Direction or azimuth between two points is inaccurate and distortion is found in area.

Conic projection, as shown in Fig. 5, maintains conformality. This projection is appropriate for mid-latitudes and regions stretching out north to south. However, distortion is generated around north and south of the projection axis; latitude lines except for the projection axis are curves; and discrepancy is generated with surrounding areas in overlaying.

Compromise projections, as shown in Fig. 6, shows less area distortion than isometric projection and less shape distortion than static distortion. This projection is appropriate for 38°

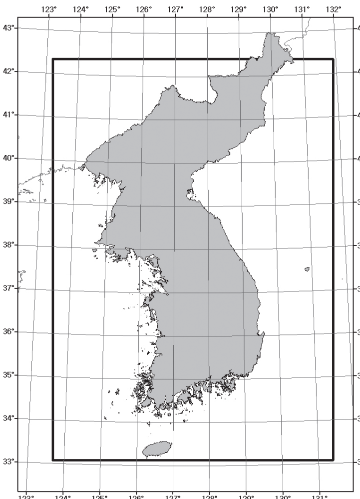


Fig. 3. Cylindrical projection results

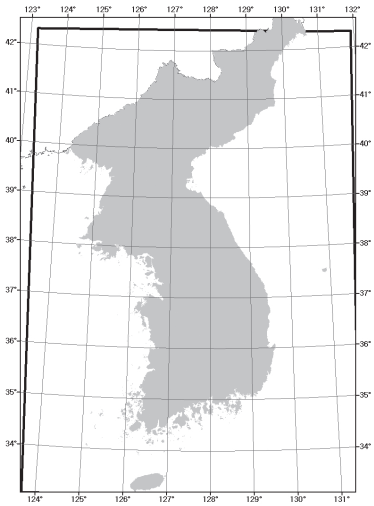


Fig. 4. Planar projection results

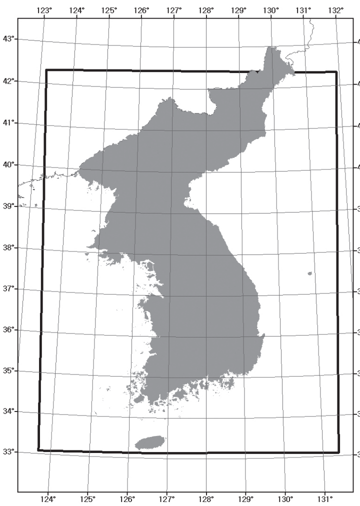


Fig. 5. Conic projection results

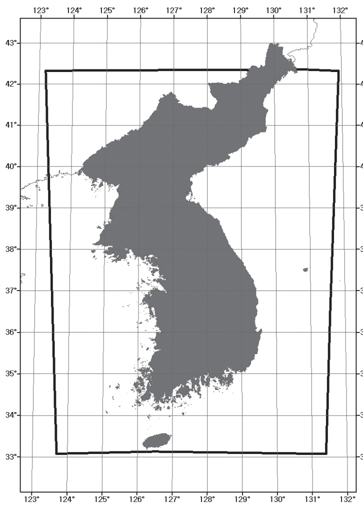


Fig. 6. Compromise projection results

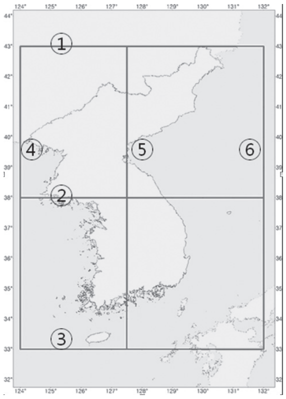
south/north latitude, but in the area beyond 38°, distance between latitude lines shrinks and its projection formula is complicated.

To analyze distortion of the shape of the Korean peninsular by projections, the scale factor by projections is compared and analyzed. For this analysis, the section is assigned as shown in Table 3 to include the entire territory of the Korean peninsular based on 127°30′ longitude and 38° latitude, the projection origin of universal transverse Mercator.

When the scale factor of 0.9996 is applied to TM projection, it is possible to use various kinds of data and DB consecutively using the universal transverse Mercator announced by the NGII, but it is impossible to print out the map in the conventional printing paper.

When the scale factor of 0.9600 is applied to TM projection, grid north and true north is matched by properly altering the scale factor; printing output is feasible; and a balanced scale factor is used between the origin and the top/bottom

Table 3. Section assignment to analyze scale factor by projections

Section	Section	Latitude	Longitude
	①	43°	124°～132°
	②	38°	124°～132°
	③	33°	124°～132°
	④	33°～43°	124°
	⑤	33°～43°	127°30′
	⑥	33°～43°	132°

projection area. However, more distortion is generated further away from the projection axis, as illustration shrinks based on the projection reference axis.

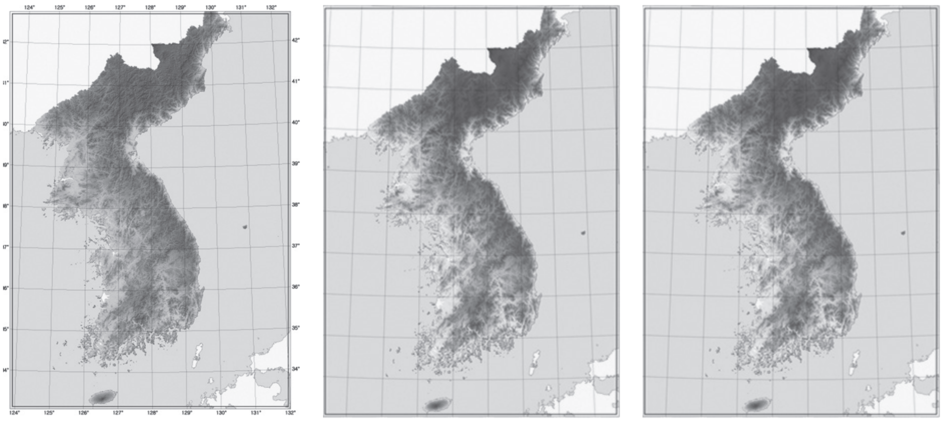
When the scale factor of 0.9794 is applied to conic projection (Lambert), grid north and true north is matched by properly altering the scale factor and printing output is feasible. However, top/bottom distortion is generated due to changed scale factor and projection and the southern area is illustrated slightly larger than the northern area, as the imbalanced scale factor is applied between the origin and the top/bottom projection area.

Scale factors are analyzed for each projection in individual sections on longitude and latitude. Compared to the currently used scale factor (0.9996) on the central meridian, as shown in Table 4, a difference of 4% on average appears when the scale factor is 0.9600 in TM projection (a-b), and that of 2% on average appears in the case of Lambert projection (a-c). This indicates that Lambert projection, instead of TM projection, can be more clearly illustrated. However, Lambert projection shows the calculation results with he scale factor of 0.9794 on 26° and 50° latitudes.

If we look at the changes in scale factor in sections in detail, as shown in Fig. 7, TM projection (0.9600) shows a similar scale factor in individual sections (0.0396 ～ 0.0397), while Lambert projection (0.9794) shows a great difference in different sections (0.0180 ～ 0.0221). In particular, the scale factor between South and North shows a great difference on the projection origin.

Table 4. Calculation of scale factors by projections

	a. UTM-K (0.9996)	b. UTM-K (0.9600)	c. Lambert (0.9794)	d.(a-b)	e.(a-c)	Remarks
①	0.9988	0.9592	0.9803	0.0396	0.0185	
②	1.0001	0.9605	0.9782	0.0396	0.0219	
③	0.9990	0.9594	0.9810	0.0396	0.0180	
④	1.0004	0.9607	0.9790	0.0397	0.0214	
⑤	0.9996	0.9600	0.9794	0.0396	0.0202	Central Meridian (Projection Reference)
⑥	1.0009	0.9612	0.9788	0.0397	0.0221	
Average	1.00	0.96	0.98	0.04	0.02	



(a) TM Projection (0.9996) (b) TM Projection (0.9600) (c) Conic Projection(0.9794)

Fig. 7. Comparison by projection and scale factor

4.2.2 Distortion quantity by scale factor

Distortion by latitude and area in Tissot's indicatrix are compared and analyzed in order to analyze accuracy in coordinate systems by scale factor when projection is made using traversing cylindrical projection. Fig. 8 shows changes in distortion by changes in scale factor.

Distortion quantity by scale factors in TM projection is analyzed by latitude. As shown in Table 5 and Table 6, an average distortion of 42.647m is generated when the current UTM scale factor of 0.9996 is used, with about 0.0384% of distortion ratio. When the scale factor is altered to 0.9600, an average of 4,438.240m distortion is generated with about 3.9985% of distortion ratio.

After reviewing Tissot's indicatrix, it is found that the

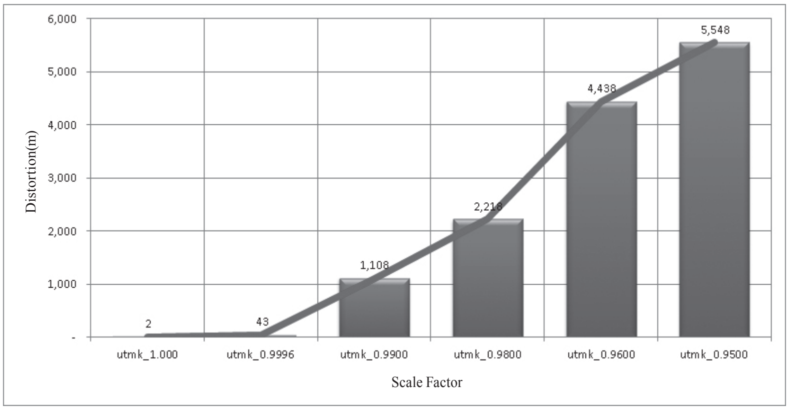


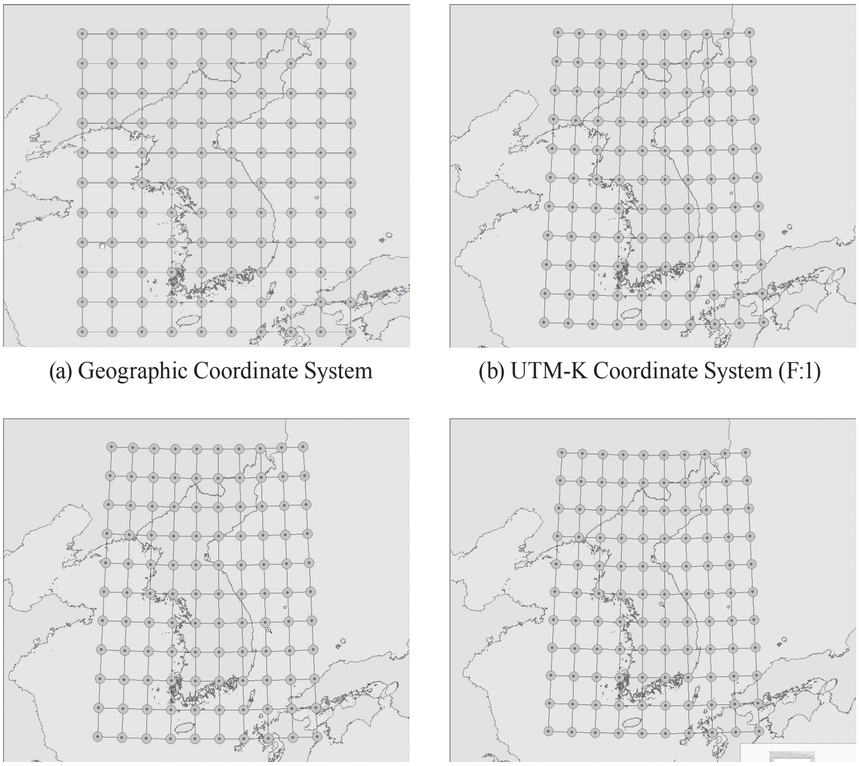
Fig. 8. Distortion quantity by scale factor in TM projection

Table 5. Distortion quantity in latitude by scale factor of TM projection **(Unit : m)**

Latitude	Scale Factor					
	1.000	**0.9996**	**0.9900**	**0.9800**	**0.9600**	**0.9500**
33°	2.069	42.297	1,107.094	2,216.258	4,434.585	5,543.748
34°	2.002	42.372	1,107.342	2,216.685	4,435.372	5,544.715
35°	1.933	42.448	1,107.593	2,217.118	4,436.170	5,545.696
36°	1.863	42.525	1,107.847	2,217.557	4,436.978	5,546.689
37°	1.793	42.603	1,108.104	2,218.002	4,437.796	5,547.693
38°	1.721	42.683	1,108.365	2,218.450	4,438.622	5,548.707
39°	1.648	42.763	1,108.627	2,218.903	4,439.455	5,549.730
40°	1.575	42.844	1,108.892	2,219.359	4,440.294	5,550.761
41°	1.501	42.926	1,109.159	2,219.819	4,441.138	5,551.798
42°	1.426	43.008	1,109.427	2,220.280	4,441.986	5,552.840
Max.	**2.069**	**43.008**	**1,109.427**	**2,220.280**	**4,441.986**	**5,552.840**
Min.	**1.426**	**42.297**	**1,107.094**	**2,216.258**	**4,434.585**	**5,543.748**
Average	**1.753**	**42.647**	**1,108.245**	**2,218.243**	**4,438.240**	**5,548.238**

Table 6. Distortion ratio in latitude by scale factor of TM projection **(Unit : %)**

Latitude	Scale Factor					
	1.000	**0.9996**	**0.9900**	**0.9800**	**0.9600**	**0.9500**
33°	0.0019	0.0381	0.9982	1.9982	3.9982	4.9982
34°	0.0018	0.0382	0.9982	1.9982	3.9983	4.9983
35°	0.0017	0.0383	0.9983	1.9983	3.9983	4.9983
36°	0.0017	0.0383	0.9983	1.9984	3.9984	4.9984
37°	0.0016	0.0384	0.9984	1.9984	3.9984	4.9985
38°	0.0016	0.0385	0.9985	1.9985	3.9985	4.9985
39°	0.0015	0.0385	0.9985	1.9985	3.9986	4.9986
40°	0.0014	0.0386	0.9986	1.9986	3.9986	4.9987
41°	0.0014	0.0386	0.9987	1.9987	3.9987	4.9987
42°	0.0013	0.0387	0.9987	1.9987	3.9988	4.9988
Max.	**0.0019**	**0.0387**	**0.9987**	**1.9987**	**3.9988**	**4.9988**
Min.	**0.0013**	**0.0381**	**0.9982**	**1.9982**	**3.9982**	**4.9982**
Average	**0.0016**	**0.0384**	**0.9984**	**1.9985**	**3.9985**	**4.9985**



(a) Geographic Coordinate System (b) UTM-K Coordinate System (F:1)

(c) UTM-K Coordinate System(F:0.9996) (d) UTM-K Coordinate System(F:0.9600)

Fig. 9. Tissot's Indicatrix distribution by scale factors

Table 7. Area change in Tissot's Indicatrix by scale factors

Section	Tissot's Indicatrix Area (㎢)			Distortion(%)	
	1.00	0.9996	0.9600	0.9996	0.9600
Average	1,076.9	1,076.0	992.4	86.1	84.4
Max.	1,080.6	1,079.7	995.9	86.4	84.7
Min,	1,073.4	1,072.6	989.3	85.9	84.2

Table 8. Tissot's Indicatrix change by scale factors

Section	Tissot's Indicatrix (a/b)		
	1.00	0.9996	0.9600
Average	0.790103	0.790112	0.790112
Max.	0.842635	0.842647	0.842647
Min,	0.732784	0.732791	0.732791

shape of ellipsoid does not change considerably in the local area as shown in Fig. 9 and Table 7. In the case of area change in Tissot's indicatrix by scale factors, about 86.1% appears with the average scale factor of 0.996, but with 0.9600, about 84.4% appears, showing some decrease in distortion quantity.

Looking at the change in Tissot's Indicatrix, a touchstone for displaying shape distortions in projections, almost no changes are found by the change of scale factor, as shown in Table 8.

4.2.3 Comparative analysis by coordinate systems

Longitude and latitude coordinate system can show the angle from the reference latitude (latitude) and the angle from the reference longitude (longitude) in illustrating a point. However, 1° difference in longitude and latitude on the equator actually corresponds to 111km of distance. Therefore, to illustrate more precise position, angles in the degree unit should be more minutely divided.

Universal planar coordinate system has the unified position reference of the national-level continuous basic geographic information, but a lot of distortions are generated for Korea because the reference origin is on the equator for projection.

It is possible to use Transverse Mercator in the National Base Map, including 1/1,000, 1/5,000, 1/25,000 and 1/50,000 scale, but due to 4 origin points, a sectional discontinuous map is generated by each origin point, leading to discrepancy in adjacent areas.

Compared to longitude and latitude coordinate system, UTM coordinate system allows calculating the distance on drawings using Pythagorean theorem more easily. On the equator, the west boundary of UTM zone is 167,000m and the east boundary is 833,000m, but the boundary differs when the zone goes to south and north.

5. Conclusion

In this study, projection and coordinate system enhancement for small-scale maps in consideration of usability and compatibility is studied and the following conclusions are drawn.

First, to make the optimum small-scale map in consideration of interrelation and compatibility with other maps, projections, coordinate systems and neat line should be refined to fit the purpose of maps by scales.

Second, when it comes to projections for small-scale maps, conic projection, a method appropriate for regions stretching out east and west, may bring out more accurate illustration than traversing cylindrical projection, a method appropriate for regions stretching out south and north, in the case of including Dokdo Island. However, considering unity and interrelation with maps in other scales, traversing cylindrical projection should be applied instead of conic projection.

Third, as for coordinate system of small-scale maps, instead of the conventional longitude/latitude coordinate system or Transverse Mercator, the World Geodetic System-based Universal Transverse Mercator should be used in consideration of unity and interrelation of maps. In addition, to accurately illustrate the shape of the entire country including Ieodo Island, the scale should be altered to 1/1,200,000 for map-making, considering the size of printing paper.

In the future, it is necessary to conduct a profound study on how to illustrate landforms and geographic features on the map with consideration of readability and visibility, in order to increase utilization of small-scale maps.

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