Informational and computational approaches to Land Consolidation

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SUMMARY

In the past decennia several information systems have been implemented in the Netherlands (and also in other countries) for informational and computational support in land consolidation projects. The paper describes and reviews the systems and underlying approaches and algorithms in relation to the evolving policy goals and procedures in land consolidation projects.

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1. INTRODUCTION

The interest of this paper lies in the procedure, or instrument, to go from the actual situation on the ground to an intended situation as designed in a land-use plan, or spatial plan. This particular procedure, or instrument, is called *land consolidation*[1] and it has close relationships with the four core functions of land management: land tenure, land value, land use and land development (Sonnenberg, 1996; Williamson *et al*., 2009). Land rights will be changed between owners and/or users, this land has a value, a use or multiple uses, and may contain improvements. Within land consolidation the exchange, readjustment or reallocation of the rights of ownership and the use of the land is the basic instrument (Sonnenberg, 2002). Rights of ownership and use of a parcel are not necessarily held by the same right holder. Whether such lease-relationships are considered in the land consolidation should be carefully deliberated (Sonnenberg, 2002; Van Dijk, 2004). In any case a strong involvement of right holders (owners, tenants and/or representatives) is a condition to achieve results based on goals.

In section 2 an overview of goals of land consolidation is given from a Dutch perspective, but in alignment to developments in land consolidation in Europe: land policies, multipurpose land consolidation and the process of land consolidation are briefly introduced. After the presented macro overview in section 2, attention is given to the information management at micro level in section 3. Information management is always related to the goals of land consolidation and to supporting algorithms in re-allocation. Many of this type of algorithms have been published already some time ago. In general the algorithms have a heuristic or optimisation basis. The paper ends with discussion on the role of the surveyor as information manager in land consolidation. One issue is that land consolidation and land management could be even more in the centre of attention of the Commission 7 today.

2. MULTI-PURPOSE LAND CONSOLIDATION

2.1 Land policy

In Western European countries land consolidation is used as an instrument for the development of especially rural areas, in Central and Eastern European countries (CEEC) land consolidation could have been used as an instrument for land reform. In rural areas the relation to land has profound implications for agricultural productivity, environmental sustainability, and the economic and social status of the rural households (Jansen *et al*., 2012).

[1] In French “remembrement” and in German “Flurbereinigung”.

Fragmentation of ownership, use or internal fragmentation (i.e. the number of parcels exploited by each user) can have negative consequences for the rural economy, but at the same time it is not disadvantageous by definition (Van Dijk, 2004). The strength of a good agricultural structure is diversity as a result of different responses to economic signals, managerial capacities, personal choices, availability of capital and family relationships (Heywood, 2000). In the case of the CEEC, land reforms distributional effects involved two separate issues: (1) the legal (historical justice) demands of pre-collectivisation land owners whose land was confiscated by the socialist governments or who were forced to participate in the collectivisation; and (2) social equity concerns (Swinnen, 1999). However, at the time of the implementation of the land reforms neither the size, form nor the location of land parcels were issues. Ideally land consolidation should have taken place simultaneously with the land reforms as it would have reduced the changes that have and will continue to take place in order to accomplish a land parcelling structure adapted to current farming techniques (Bullard, 2000). Land policies that are enabling diversity and change are likely to be more successful in fostering rural prosperity than policies predicated on some specific economic model (Heywood, 2000).

2.2 Development from single to multi-purpose land consolidation

The improvement of the agrarian structure, i.e. land-use structure, and thereby raising the agricultural production level, decreasing production costs and increasing farming efficiency was the main purpose, or mono-functionality, of land consolidation (Van Lier, 2000). Legislation concerning inheritance led, and leads, in most countries to a worse parcel structure over time, unprofitable parcel sizes and shapes, and unfavourable distribution of parcels within a farm holding. After the Second World War the application of land consolidation in public programmes resulted in economically-sized agricultural holdings in North-western Europe. Enlargement of scale, specialisation and intensification were the most visible developments in farming, demanding a rearrangement of spatial entities. The main driving force was the improvement of the annual income position of the farmers (Van Lier, 2000). The land consolidation process was generally implemented via Acts of Parliament and guided by governmental support.

In the 1960s agricultural over-production and environmental demands led to a shift from the main focus on improvement of the agrarian structure and livelihood of farmers to measures to improve the landscape and natural conditions (nature preservation or rehabilitation, etc). The direct effects of farming methods and indirect effects of land consolidation programmes had a negative effect on the quality of natural resources, and sometimes human resources, in the rural areas by leading to erosion and land degradation, pollution of water, soil and air, biodiversity losses and losses in landscape and recreational values (Van Lier, 2000). It became clear that farming practices needed to be changed and consequently land consolidation programmes. Thus land consolidation had to find a balance between development and conservation issues, consider the attractiveness of rural areas for future generations (sustainability paradigm) and consequently it became *multi-purpose* oriented enhancing the whole lay-out of rural areas (Van Lier, 2000). In the late 20th century land consolidation projects in the Netherlands became tailor-made to specific areas with very specific objectives (for example reconstruction of greenhouse areas). FAO (2003) speaks about ‘comprehensive land consolidation’. This includes ‘the re-allocation of parcels together with a broad range of other measures to promote rural development. Examples of such activities include village renewal, support to community based agro-processing, construction of rural roads, construction and rehabilitation of irrigation and drainage systems, erosion control measures, environmental protection and improvements including the designation of nature reserves, and the creation of social infrastructure including sports grounds and other public facilities’.

Apart from comprehensive land consolidation there are other approaches as simplified consolidation, voluntary group consolidation, and individual consolidation initiatives (FAO, 2003).

Land consolidation changed over time as policies changed. It moved from the agricultural sector into the environmental and recreational sectors. In addition to the economic role of agriculture to supply food and fibres, it is now involved in the comprehensive renewal of the rural economy and landscape (Fischler, 2000). The restructuring of land and farm holdings is a *dynamic* process, which is taking place constantly and for all kinds of socio-economic reasons (Heywood, 2000). For land consolidation participation is absolutely necessary and its implementation proved successful only where stakeholders and beneficiaries are involved in the decision-making processes and existing, informal approaches and schemes are recognised and integrated into local democratic governance institutions (Riddell and Rembold, 2002). In countries with land consolidation legislation this is formalised since many decades; see for example the contributions in Van der Molen and Lemmen, (2004a). Kovács and Osskó (2004) state very clear in relation to an evaluation of land consolidation pilots: after 50 years of collectivisation and bad memory of “socialist land consolidation” the new land owners did not show too much interest in the project. Land consolidation can be implemented on voluntary basis. There are similar experiences in other CEEC countries, it is therefore recommended starting land consolidation only on (complete) voluntary basis (FAO, 2003).
Thomas (2006a, 2006b), in his comparative study identifies as objectives in land consolidation in Western Europe:

- improvement of production and working conditions in agriculture and forestry,
- improvement of the general use of land in rural areas,
- maintenance of existing and creating new employment in rural area’s,
- improvement of the livelihoods of the rural population, and:
- conservation and protection of the natural and cultural legacy.

2.3 The process of land consolidation

The land consolidation process starts with agreement on the area involved and comprises in general: (1) preparation and voting of the land-use plan in a specific area, (2) inventory of the (ownership, use) rights on the land and the valuation of the land, (3) drafting and confirmation of the reallocation plan and other functions to be realised, (4) implementation of the reallocation plan and creation of other functions, (5) financial arrangements taking into account the benefits, and (6) registration of new titles. See also Box 3 in FAO (2003). In the process there are several moments in which persons can file objection to what is being proposed to them. Such objections need to be solved before the next step in the process can be made. For example: it has to be clear who is participating and for how much from the inventory before a re-allocation plan can be designed. This is only clear after all complaints have been processed – but it is of course always possible to be practical here. See also Jansen *et al* (2010).

The redistribution of the land according to the ratio of each one's contribution, i.e. proportional distribution, to the total is an important characteristic of the reallocation process. This reallocation can be based on the area or on the value of the land. The proportional distribution incorporates the possibility to reduce each portion that has to be redistributed with a percentage in order to acquire land that can be used for uses having a public interest (for example water management systems, new roads or bicycle paths, new recreation facilities). Such a reduction is called systematic reduction. But it is also an option to use *governmental land* in the area where land consolidation is executed for the realisation of provisions in the public interest. Reallocation of such governmental land can take place to where these provisions need to be established. In advance the government can buy land in the area and this will reduce the amount of land to be acquired by systematic reduction. However, governmental land can also be used to enlarge farms. Differences in land in terms of topography and quality limit the possibility of reallocation. Therefore often a quantified discrepancy between the reallocated portion and the reallocation claim is permitted.

3. INFORMATION MANAGEMENT IN LAND CONSOLIDATION

3.1 Spatial planning context

Sonnenberg (1996) emphasises on the role of the surveyor in land consolidation. Most of the activities of the surveyor can be characterised as being a registrative or recording nature, like surveying, mapping and land registration. The cadastral surveyor normally registers or records what others have changed. In land consolidation the surveyor plays an active role in changing the ownership and use of the land which can lead to physical changes. Sonnenberg highlights that planning is normally related to spatial, or physical, planning and is thus indicating the design of an intended physical situation, but it does not include the way (the instrument or procedure) how to get from the initial (existing) situation to the intended situation. The surveyors activity is in fact the implementation of the planning objectives by procedures that effectively result is a changed or renewed land ownership and land use which of course must be in accordance with these objectives. See section 2 above for examples of objectives in (multi-purpose) land consolidation.

Thomas (2006a and 2006b) also looks at land consolidation as the combination of land readjustment plus special (agrarian) physical planning. In regard to the term 're-adjustment' it should be noted here that this is called re-allotment or re-allocation in other publications. Sometimes 'land re-adjustment' has a focus to urban areas. Through special physical planning the administrative basis for all intended agricultural measures is done and, if needed, legally regulated and enforced. The land readjustment component is the core issue of each land consolidation approach; land readjustment allows a realisation of the physical planning; in land consolidation the adjustment of the land tenure occurs in the land readjustment segment. Thomas (2006a, 2006b) states that thorough transformations and measures are not possible without consideration of the land ownership and land tenure structures and rights. For this reason most of the European land consolidation laws have combined the spatial planning and re-adjustment tools.

The following should be considered:

- the policy being conducted concerning the land consolidation process (general goals as a result from spatial planning and spatial restrictions from landscape, nature, etc). In a comprehensive land consolidation areas planned for specific purposes (nature preservation, extensions of infrastructure or elements in landscape, irrigation, etc) can be identified, the value of those areas can to be calculated to know the systematic reduction for general or specific purposes. Value is meant as value for exchange purposes. Systematic reduction can be an important tool to get land available for non-agricultural purposes. This can be combined with an active land purchase policy by a land bank. Available land in the bank can be re-allocated to achieve goals in a win win combination with farmers. Apart from comprehensive land consolidations there are more and more projects that are completely voluntary based. This means the supportive tools in the decision-making process need to be flexible too: working together with the participants in an interactive way (touch screen or beamer) should be possible,
- continuous link with the ownership data in the cadastral and land registry system. The land market is ongoing while the design of the intended situation for implementation in the field is being prepared – this concerns not only real rights as property but also the actual land use; the linking should be integrated with valuation data (for example based on a soil map) in case a valuation is applied as a basis for exchange. It is complex to manage the impact of buying/selling transactions in the existing situation of the design; especially because the design may be used on actual land use and not only on the properties. Strengthening the *de facto* land use requires a good protection of tenants (tenancy or lease contract should be for longer time). It should always be remembered that the actual land user produces the crops; this is not only done by the land owners. Concentration of plots and distance reduction to farms should (could) be applied to land use for this reason; this results in improvement of the agricultural structure,
- preferences, of entitled parties (the ‘demand for land’ as claims for re-allotment that have to be brought in balance with the ‘supply’ of land. It should be noted that preferences can be expressed by representatives. Supply of land is available in allocation compartments. The way in which preferences are discussed with entitled parties is directly related to the implementation of spatial planning: infrastructure, nature and landscapes and water management need space at specific locations. This has to be agreed with entitled parties, the land users included,
- the contributed value per party, the total contributed value per entitled party has to be re-allocated within certain margins (see also Jansen *et al*, 2010). Those margins are not the systematic reduction but allowed margins in proportional distribution (voluntarily or as allowed by law). Value may be calculated from soil quality, there may be impact of

market value. In areas with only small differences in fertility the proportional distribution can be area-based, and:
- public inspections to check the parcels per right holder (owner, tenant), the contributed total value per right holder, the proposed allocation and the financial arrangements have to be prepared. This includes also a list of parties with voting rights; for example in case of comprehensive land consolidation. One issue here is that the land market is ongoing. For this purpose the data for public inspections have to be ‘fixed’ at a certain date and then these data can be prepared for public inspection. At the same time the actual people-land relationship can change (for this reason the link with the cadastre and land registry is needed).

3.2 Information management

The requirements for support of the decision making process (design process) in land consolidation may include (Lemmen, 1990, Tenkanen, 1990, Hoisl, 1994, FAO 2003, Jansen *et al.*, 2010):
- the representation of multiple themes, for example: existing ownership and land use (including mortgages, easements, informal rights that are not yet registered) and transactions there on, the allocation compartments, the traffic network, tree stands, nature elements, the valuation (based on uniform fertility), the structuring of values for allocation purposes. Further there is a need for a large scale topographic map with height contours or at least areal photos of the existing situation. Each theme contains spatial and administrative data. Management complaints requires separate themes,
- the representation of preferences of entitled parties. This concerns the total contributed value per party and (alternative) allocations of (parts of) this contributed value in (alternative) allocation compartments. In other words the Persons-GroupPersons-Rights-newParcels relations – that can be very complex and that are dynamic during the design because of the ongoing land market (which in itself can be in support of the goals of land consolidation,
- the design of the new situation. If re-allocation algorithms are applied (see section 3.3 below) interaction between the land consolidation database and the model applied is needed; this means generating input data and inclusion of the output (results) of the algorithm. The design needs to be transformed to a new cadastral situation which includes all original real rights and mortgages, and:
- survey data, this concerns both acquisition and management of boundaries to be implemented (set out) in the field.

The knowledge built up from the development of the Land Administration Domain Model (LADM, see: Lemmen *et al.*, 2010a, 2010b, Lemmen, 2012, Van Oosterom *et al.*, 2011 and ISO, 2011) seems to be very useful for information management purposes in land consolidation. One could develop a Land Consolidation Domain Model based on LADM.

A first analysis learns that in LADM the class LA_SpatialUnitGroup can already be used to group a set of spatial units (parcels) together forming an administrative zone such as a section, a canton, a municipality, a department, a province, or a country. But also all spatial units within a planning area; this can be a complete land consolidation project area. In this way it is known that a spatial unit is within a project. This is relevant in information supply to potential buyers because of possible legal impact and can have as impact that a parcel that is bought can be re-allocated. A LCDM has in principle the same structure and classes as the LADM; there are some extra attributes and codes. And some of the class names and multiplicities are different. This makes interaction between LCDM and LADM very easy: allocation compartments can be identified as spatial unit groups (hierarchic identifiers can be used). In this way the land consolidation project area is also known in a cadastral/land registry system. All changes in the people-land relationship can be easily detected using available LADM functionality as time stamps, source documents describing transactions or LA_RequiredRelationship identifying the link between old and new situation within a transaction.

Automatically all entitled parties (LA_Parties), Right-Restrictions-Responsibilities (RRRs, including ownership, easements and mortgages etc), properties (LA_BAUnits or basic property units including all spatial units/parcels per party) and the spatial units (LA_SpatialUnit) are known if a spatial unit group is created based on the boundaries of the land consolidation project.. Those BAUnits include the spatial units of involved parties outside the project area, but new BA_Units may be formed in a separate set up of the LADM especially organised for the land consolidation project area.

In LCDM we have the following first draft requirements (prefixes below are LA to understand the link with LADM, in a LCDM prefixes could be LC, but this is only an idea in this moment):

- extra attributes for value are needed in LA_SpatialUnit (a spatial unit can be a parcel); because in the LADM value is related to an external database; in LCDM this should be available as an attribute (because the value has a meaning within the land consolidation),
- the multiplicity between RRR and LA_BAUnit should be 1…* in both directions. This sounds technical, but it means in principle that one LA_RRR can have several LA_BAUnits, this allows for representation of preferences into farm models. The different BAUnits are alternatives in allocation per farm,
- the code list in with an overview of types of BAUnit should be extended with farm models. Farm models are alternative structures per farm, each model per farm has allocations for associated spatial units in alternative allocation-compartments. Values in the code list will be: ExistingFarm, FarmModel1, FarmModel2, FarmModel3, …, ImplementedModel. This is also possible if the alternatives are not farm-based but spatial unit based. The associated spatial units in farm models are point based or text based, the spatial unit id contains a link with the allocation compartment,
- holders of land-use rights can be included. Related right types can be included in the code list LA_RightType, eventually in LA_RestrictionType or Responsibility Type, as far as not yet available,
- total contributed values can be derived from values per spatial unit in the existing situation,
- LA_Level should include levels for soil value, the associated spatial units are areas with equal values, and:

- LA_Level should include one level where the new situation can be designed based on FarmModels which should be implemented. Levels for management of complaints are needed.

3.3 Allocation algorithms

Many allocation algorithms in support of the design of a re-allocation plan have been published:

- Finland (Tenkanen, 1987),
- France (Ludot, 1971),
- Germany (Hupfeld, 1971) and (Schrader, 1971),
- The Netherlands (Kik, 1971, 1975, 1979), (Lemmen and Sonnenberg, 1986), (Van Beek and Wientjes-Van Rij 1980) and (Van der Schans, 1971),
- Morocco (Essadiki, 2002), and:
- Turkey (Ayranci, 2007, Kusek, G., (presented at a GIS conference in Tirana, Albania) and Cay *et al.*, 2006).

Van der Schans (1975) and Hoisl and Nadolski (1994) give overviews.

A distinction in approaches can be made: heuristic approaches or optimisation approaches. Heuristic approaches are based on experiences from manual approaches and optimisation approaches are mostly based on linear programming where a linear objective function is optimised (e.g. distances minimised or concentration of lots maximised). Methods used from operations research are the transportation algorithm, the stepping stone algorithm, mixed integer programming, simplex method. It is very interesting to see that further developments take place in Turkey today. Large scale land consolidation is under process in Turkey, see Jansen *et al*, (2010).

Some examples of algorithms developed in the Netherlands are worked out below.

An example of an optimisation approach is provided by Kik (1971, 1974, 1979). The average distance between the farmhouse and allocated plots is minimised in such a way that the number of plots is minimal. The applied stepping stone algorithm is not so easy to understand for allocation experts. But the approach proved to be useful in exploration of the possible effects of land consolidation. This method is useful for the calculation of costs and benefits of land consolidation (during preparation of projects). Data input is based on actual land use.

An early example of a heuristic approach is the system for Automation of the Re-allotment Plan for Land Consolidation, abbreviated in Dutch to ATOR (Van der Schans, 1971; Van der Schans, 1975; De Vos, 1981). This concerns the administrative plan: who can be allocated for how much and where? The input data for the calculations are based on the total contributed value, this is the claim for allocation. This total contributed value is (can be) subdivided in parts. This division can be based on a model (e.g., 60% near the farmhouse, 40% at distance). Or the division can be based directly on preferences from right holders. Those preferences represent the vision of the farmer on the future structure of the farm. Input data are: the value of desired (or modelled) parts, alternative locations of desired parts and weights that can be related to each location (weights are given on the basis of existing and desired situation). Those data concern the demand for land. Supply of land is represented by data on allocation compartments; each compartment has an identifier (needed for the location of desired parcels) and a value. Demand for land should be in balance with supply of land. Land banks can facilitate this process. The allocation of parts of the total contributed value is in line with goals to be achieved, for example to get lands available for non-agricultural purposes or to get optimal agricultural structure.

An initial solution can be calculated in ATOR based on the locations of the desired parts with highest preference. This will result in an allocation compartment with a higher demand then supply and the other way around. The differences between supply and demand are called residuals. Transfers are applied now between different alternative allocations of desired parts. All possible transfers are calculated. The transfer with the highest reduction in residuals will be selected (this can be more complex in case the weights are included in the selection of transfers). The process will stop if no transfer is available which can reduce residuals. The spatial design of boundaries can be based on the outcome of the application of this algorithm (Lemmen, 1986; Lemmen, 1990; Jansen *et al.*, Rosman, 2012).

The ATOR system has proved to be useful in re-allocation in many land consolidation projects. Input is based on actual land use. Allocation can be based on farm models. This is supportive in recognition of bottlenecks in re-allocation. This is important information in case new farms can be constructed. A detailed application based on preferences of entitled parties is possible too, this is the basis for the spatial design. The method is easily understandable by re-allocation experts because it is based on the manual approach (as applied decades ago now). The ATOR system has been further developed into the system TRANSFER, as will be described below.

Another approach is available in the Allocation and Adjustment Model (Lemmen 1986), in Dutch abbreviated as AVL. Solutions are calculated based on methods from operations research (mixed integer programming). For each farm alternative farm models are defined based on farm modelling or on preferences of parties. Each farm model is related to the total contributed value for that farm. Each farm model concerns a complete farm; a farm model is in fact the smallest unit (not the parts as in ATOR). Locations within one farm model are flexible now within given margins, for example 50-70% near the farmhouse, 30-50% at distance. This is not possible in ATOR. For each farm only one farm model can be selected in AVL under the condition that the allocation compartments have residuals within a given margin (each allocation compartment should close within ± 5% of its value). It may happen that the solution space is empty. The goal is to select as many farm models with a high priority (given the preferences which can be derived from the preferences of the farmers) as possible.

The AVL system is very flexible in the representation of preferences of entitled parties. The applied algorithm (mixed integer programming, with a comprehensive mathematical model) is difficult to understand for re-allocation experts. The system has been used in practice in a few projects but is no longer operational.

The approach in TRANSFER *combines* the benefits of both ATOR and AVL. In practice AVL can be complex in use, because the solution space is empty in case there are insufficient, or too many, requested values in an allocation compartment. In that case no balance between demand of land and supply of land can be calculated because the total value of allocated lands in one allocation compartment has to be equal to the value of that compartment within margins In TRANSFER it is possible to use the heuristic approach from ATOR combined with flexible parcel-values as in AVL. This makes the approach easy usable in practice. In step by step discussions with farmers the residuals can be minimised (almost equal to zero). This is a good basis for re-allocation. The TRANSFER system has been applied very successfully now since many years in Land Consolidation in the Netherlands, also in case of complete voluntary land consolidations - that are more or less mainstream nowadays.

TRANSFER is operational now in the Netherlands' Kadaster as a basic re-allocation algorithm. The system is under further development where the calculation of the position of boundaries is concerned (Rosman, 2012).

Land available in the land bank can be allocated in areas with with new types of land use. The farmers in those areas can be re-allocated. This can be combined with systematic reductions and availble lands from this. Entitled parties will get compensations of course.

Boundaries of allocation compartments are chosen in relation to existing topographic features or feautures to be implemented.

Important is a good interaction between the database with spatial and administrative data in land consolidation and the algorithms (solution spaces). This implies also a link with a Land Information System with ownership and land-use data.

4. DISCUSSION

Multiple goals can be achieved with land consolidation. This has impact on the spatial development, the economy and the livelihood of people in the area.

Land consolidation can serve many goals on macro level if sufficient financial resources are available. Via systematic reduction, land bank and other measures land can be 'converted' from agricultural use to other types of use, as infrastructure, landscape, nature, leisure, etc. Or the other way around. The structure of farms can be improved by concentrating land and by distance reduction. This can be combined with other goals if allocation compartments are chosen properly. Participatory approaches are very well possible: solutions for allocation can be immediately calculated during discussions with right holders.

A discussion on information management aspects remains relevant within FIG: land consolidation is expected to be applied more and more given the population growth and the expectation that the total amount of agricultural lands cannot grow substantially. This means efficient use of the limited resources of land.

It may be useful to develop a domain model for land consolidation based on the LADM. Such a model includes the data for representation of the existing situation (*de facto* land use), the valuation data, the input alternatives for re-allocation algorithms (based on models or preferences) and the final result of land consolidation for implementation in the field and inclusion of the new situation in the Cadastre and Land Registry. A combination of a Land Consolidation Domain Model, based on the LADM[2] (ISO, 2011), allocation algorithms and a strong link with cadastre, land registry and a tenant registration is a good basis for information management in land consolidation. Surveyors play a key role here. Research is needed to develop a Land Consolidation Model and also for possible use of ISO 19144-1:2009 on classifications for a proper representation of valuation data (ISO, 2009). This means a combination of a domain model, allocation algorithms and a good representation of valuation as a basis for information management in support to multi purpose land consolidation.

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[2] Expected to be available as International Standard around July 2012

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