Mat-2.117 Operations Research Project Work Seminar
Helsinki University of Technology

FORECASTING MARKET DEMAND FOR MOBILE BROADCAST SERVICES IN FINLAND

Final Report

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Abstract

This is the final report of the course *Mat-2.177 Operations Research Project Work Seminar* in Helsinki University of Technology. The aim of the project work is to forecast the market demand for the mobile broadcast (DVB-H) services. The client is TeliaSonera Finland who is also one of the companies building the DVB-H test network that will be operational in late 2004.

Establishing such a forecast would be extremely difficult even in much better defined conditions. Traditional, theoretically well grounded frameworks do not apply here. The current forecast has to be established in lack of almost any time series data.

The present study is thus divided into two complementary parts. The quantative analysis deals with the mathematical diffusion models, which basically are simplified but detailed analysis of the service adoption development. These models try to capture the essentials of previous analogous new product launches and the consequent demand growth. The analogies were carefully selected to correspond the characteristic features of the planned DVB-H service. A weighted average of estimations are used in the final forecast.

The analogous cases used in this study are the market penetration of the Sony Walkman and DIRECTV, which resulted in cumulative adoption level of 10 % in 3.3 years time after product launch and 90 % adoption was reach in 16.4 years. The inflection point is found somewhere at 8.8 years; this is also the time when the prediction is most inaccurate. The maximum achievable adoption level for DVB-H is a coarse estimate of 63 % of the population. The confidence intervals are very wide, as expected.

The qualitative part is studying the markets and value system. The purpose of this part is to evaluate essential dependences between significant variables e.g stakeholders, pricing, coverage and service adoption mechanisms. Key interest is in finding potential show stoppers and point out areas, which may make the quantitative part over optimistic.

The most severe identified potential show stoppers were inadequate pricing, lack of proven use case and insufficient coverage. In addtion to this, the product itself has to meet user requirements.

Contents

1 Introduction

Mobile broadcasting is an inexpensive way of distributing lots of data at high speed. The effective bandwidth is around 11 Mb/s [16]. Basic functionality is similar to Digital Video Broadcast Terrestrial (DVB-T) network, which is being deployed throughout Europe. The special version, called DVB-H (hand-held) has been made to support portable and mobile devices with small integral antennas only. Service will be provided with extended mobile terminals, which include DVB-H receiver additional to normal cellular radio. End user may use the mobile phone part to choose the content they wish to view and then they can use the DVB-H part to receive the content.

Converging digital content formats, networks and connections using Internet protocols, and all devices having wireless communications capabilities are the disruptive technologies jointly fuelling the new business opportunity. Value systems are being restructured as the same content is accessible through any type of connections: physical, fixed Internet, cellular systems, digital broadcast - or a combination of any of the above. This research project is focusing on the combination of DVB-H and GSM/GPRS/WCDMA. Regional differences in technology arise due to differences in existing principal technologies.

Forecasting market demand and service adoption in Finland is needed to justify the investments to the proposed concept. This project builds a framework and basic model for such as purpose. The challenges lie in the fact that there exist no data on the subject today. The technology is new and it has not been implemented anywhere. A test network has been built in Helsinki by Radio- ja televisiotekniikan tutkimuskeskus. Since September 2002, they have sent test DVB-H broadcasts. At the moment the test terminals consist of a PC and DVB-H receiver. The end user experience is only partially comparable to the planned service. In October 2004 a pilot service has been planned, in which friendly test customers will be able to use portable devices to receive the DVB-H broadcast and to control their services with the mobile phone built into the same device.

The framework and model developed in this project can be used to provide some forecasts based on analogies found in the history of consumer goods in the area of communication and entertainment. The model may be developed further when some data is available, first based on the pilot service and later from the real service. Diffusion models show adoption in graphical form. Since there is no time series data available today, a value system based analysis is also carried out to give some qualitative measures, which can be used in order to filter out unrealistic results.

The final report begins with the definition of the studied service in section 2. Then we discuss general service adoption models in section 3. Also the fundamental diffusion models are presented and the reasoning how and why such models can be used to explain market development of new technologies and services.

The market forecast is at this phase based into large extent to diffusion models, where the parameters have been estimated using analogies with similar technologies. Developing the models and their parameters is the main topic of section 4.

Section 5 looks at the proposed service and related applications. Also the technology options are discussed briefly. The main focus in section 5 is on the value system and especially in the issues related to combining broadcast and mobile communication value chains together. Also other important factors impacting the service adoption are discussed, such as pricing, end user device capabilities as well as system support capabilities.

The forecast for the market development is presented in section 6. The section then continues with a sensitivity analysis. Potential errors and risks in the model are also discussed.

Finally in section 7 some recommendations for future work are provided, both how to improve the service to potentially increase the diffusion rate as well as how to improve the forecasting and the models when more facts become available.

2 Service Definition

Broadcast services give low cost connections from one transmitter to many receivers. The same content is distributed to everybody at the same time. Therefore it functions like a television or radio channel or like text-TV. It does not give the same functionality as the internet or peer-to-peer networks.

We will focus on the mobile television application. There are a number of MUX's in Finland. These are broken into pieces which each have a certain capacity [Mb/s]. All but one of the MUX's are distributed to television content providers. The one that is left will be used for the mobile broadcast activities. Because mobile broadcast TV channels do not require as much bandwidth as traditional television channels, it is possible to broadcast much more channels within the one MUX that is reserved for mobile broadcast services.

The end-user devices that we assume to be used with with this service are of the same size and have the same usability as Nokia 7700, the television cell phone. The end-user devices will be bought from consumer electronics stores and they will use a SIM card (supplied by a cellular operator) for identification. Interactivity is provided to the user with the GPRS-capability of the end-device. The user will have to pay the normal GPRS-fare to for data transmissions over the GPRS network. Three basic service packs have been hypothesised:

Service Pack 1 Basic Digital TV (all DVB-T open radio and TV channels)

Service Pack 2 Service Pack 1 + Interactivity

Service Pack 3 Service Pack 2 + pay TV channels

The costs of the service packs are described in more detail in a later section about pricing (section 5.5). Mostly the Service Packs will follow the prices of GSM subscription, GPRS monthly fee and pay TV monthly fee.

3 Service Adoption

Market demand cannot be estimated based on the external factors only. Service adoption has many internal mechanisms, which can be modelled using differential equations. These equations will provide quantitative estimations on the speed of diffusion of the new technology and the service it supports. However, these models are very difficult to use in this early phase because there is no hard evidence yet available on the parameters for the current case. Analogies with earlier similar cases may be used to give connections to the real world. Parallel qualitative estimates and especially identification of potential show stoppers will provide valuable second opinion.

3.1 Diffusion Model

The object of a diffusion model is to present the level of spread of innovation among a given set of prospective adopters over time. Early models, like the Bass model [1], attempted to describe the penetration and saturation aspects of the diffusion process. A diffusion process consists of four different key elements [11]

1. innovation
2. communication channels
3. time
4. social system

Diffusion theory's main focus is on communication channels, which are the means by which information about an innovation is transmitted to the social system. Both mass media and interpersonal communication are relevant in this topic.

Research of the diffusion models has concentrated in four areas. The areas are [11]

1. Consumer behaviour. Researchers have been concerned with evaluating applicability of hypotheses developed in the general diffusion area to consumer research.
2. Marketing management. Implications of the hypotheses for marketing new product prospects and for developing marketing strategies aimed at the potential adopters.
3. Analytical models for describing and forecasting the diffusion process.
4. Normative guidelines. How the innovation should be diffused in the system.

The Bass model and its development

Since the publication of the Bass model, researchers have extended the model. Different variations include at least:

1. Basic diffusion model (Bass). The Bass model explicitly considers the influence of internal and external sources of communication on innovation of diffusion.
2. Parameter estimation. Parameter estimation has two sections: if no prior data is available and if data is available. Parameters can be estimated using either time-invariant or time-varying procedures. Methods to be used are considered from situation at hand.
3. Flexible diffusion model. The Bass model assumes that the maximum penetration rate cannot occur after the product has captured 50 % of the market potential. A flexible model allows the maximum penetration rate occur at any time during the diffusion process.
4. Extensions and refinements of the Bass model. The innovation process has several topics to be considered since the Bass model has several underlying assumptions which seriously undermine its applicability especially as a forecasting tool. These topics are briefly [11]:
   - Market potential of new product remains constant over time.

- Diffusion of innovation is independent of all other innovation.
- Nature of an innovation does not change over time.
- The geographic boundaries of the social system do not change over the diffusion process.
- The diffusion process is binary. Adopters either adopt or do not adopt the innovation.
- Diffusion of an innovation is not influenced by marketing strategies.
- Product and market characteristics do not influence diffusion patterns.
- There are no supply restrictions.
- There is only one adoption by an adoption unit.

5. Use of diffusion model. Innovation diffusion models traditionally have been used in sales forecasting. In addition to forecasting diffusion models can be used for descriptive and normative purposes.

The diffusion model discussed here has traditionally been used for forecasting the first-purchase sales volume. As the diffusion models capture the dynamics of an innovation diffusion for the first-time buyers, it is not clear that the same model and dynamics are applicable to replacement sales. Also recent development in the global context, "globalisation", has made some researchers suggest that the use of Bass model is inappropriate in international settings. Finally, the diffusion models are imitation models. An arbitrary s-shaped curve might not be the result of an imitation process, and therefore some alternatvie time-series models may be more appropriate in such a case.

Bass model

End user segments are often studied by analysing the adoption curve or learning curve. The Bass model assumes that potential adopters of an innovation are influenced by two means of communication: mass media and word of mouth. Bass termed the first group "Innovators" and the second group "Imitators". Rogers articulated that Imitators should be divided in four categories. That is, Innovators are at most 5 % of the potential adopters. [1, 13]

The Bass model derives from a hazard function. Thus,

$$\frac{f(t)}{1 - F(t)} = p + qF(t) \tag{1}$$

The density function of time to adoption is given by $f(t)$ and the cumulative fraction of adopters at time t is given by $F(t)$. This states that the conditional probability of an adoption is increasing in the fraction of the population that has not yet adopted. The basic assumption in adoption process is that it is symmetric with respect to time around the peak time t^*. Rogers has articulated that the adoption curve should have a normal distribution. Figure 1 shows the customer segments divided by the normal distribution.

Initial purchases of the product are made by both innovators and imitators. The important difference between an innovator and an imitator being the buying influence. Imitators are influenced by the number of previous buyers while innovators are not, in the timing of the initial purchase. The first term in equation (1) represents adoption due to buyers who are not influenced by the number of people who already have bought the product. Bass referred to p as "coefficient of innovation". The second term represents adoption due to buyers who are influenced by the number of previous buyers. Bass referred to q as the "coefficient of imitation". [1]

3.2 End User Segments

End user segment are often divided in following manner. Characteristics of the end user groups according to Geoffrey Moore [12] are briefly as follows:

Technology Enthusiasts are sometimes called Innovators. These are the people who fundamentally commit to new technologies assuming that sooner or later these are needed to improve their lives.

Visionaries are also early adopters. Visionaries make a larger group and also more serious group than technology enthusiasts. Visionaries are important because their motivation to adopt the new technology and service is based on the improved value and they are willing to pay also for the service, not only for technology itself. Innovators and Visionaries represent the early market, which sometimes is considered to be up to 10 % of the total market size.

Pragmatists , or early majority, are the most important people to push the diffusion of the new technology to the inflection point. Pragmatists want to see some concrete evidence that the service really works and that it will bring the promised benefits. Social networks are important for pragmatists in the decision making process. Pragmatists also believe more in the evolution than to revolution. Proven used cases are very important. Pragmatists also will rely on known brands and most likely to select the market leader's solution.

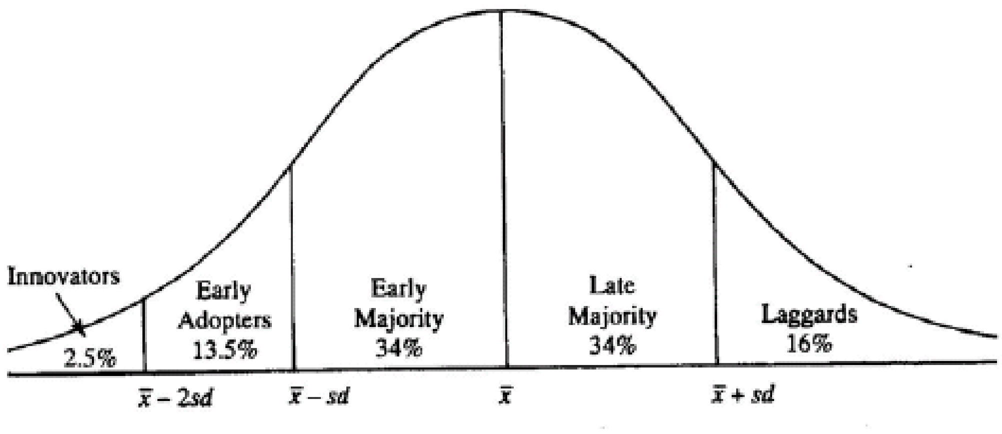


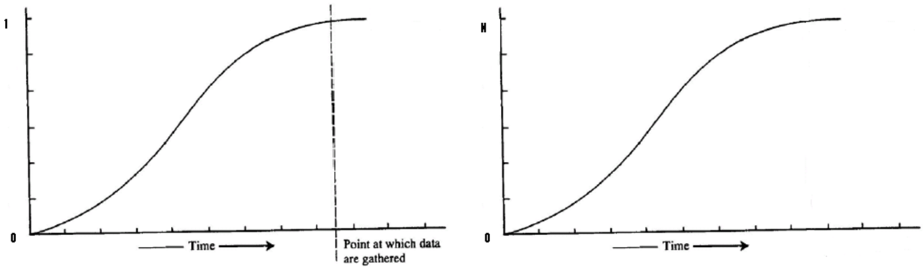
Figure 1: End user segments.

Conservatives are also called the late majority. These people typically first think about the negative factors of technologies. They actually will buy technologies but not because of the technology but merely in spite of it. For conservatives it does not make any difference whether the technology is broadcast or cellular or any other similar issue either. They have to get the service they want. Value of the old and new services, both, is important. They have no extra budget for high tech but they may have extra budget for mobility, in case they can benefit the service while on move. Conservatives, however is very important group because they consist roughly 50 % of the total market.

Sceptics or laggards, is the most difficult customer group. They will adopt the service as last, in best case. It may be reasonable to expect that some portion of the consumers simply never subscribe.

The end user segments are presented in Figure 1 as a fraction of the total population. It coincides well with the s-curve of diffusion theory. The derivative of the cumulative diffusion, $f(t)$, has the same form as in Figure 1. The different end user segments adopt a new technology at different times, but the people within a group adopt more or less at the same time. The different sizes of the different groups result in adoption rates described by the diffusion model's s-curve.

The first two groups will adopt the service sooner or later. Therefore one may assume that at 10 % penetration level it is already quite possible to forecast how the rest of the end user groups will behave. This is in some cases so, but for many technologies it has been noticed that a so called “Chasm” (silent period before pragmatists enter the adoption phase) exists. Factors, which often make



(a) (b)

Figure 2: Different type of diffusion models. (a) replace product (b) brand new product.

the stumbling block in this phase, are the same, which prohibit the holistic usage of the service. The primarily idea how to cross the “Chasm” according to Geoffrey Moore is to think about the service in the form of “Whole Product”. This means that the service and the end user product has to satisfy at least some user’s needs 100 %. It is better to be exactly right for one service rather than being almost right for many. Assuming that the “Chasm” may be crossed successfully, this point may also be suitable to forecast rest of the diffusion parameters based on the time series of data already available. [12]

The Bass model has a key aspect that it addresses the market in the aggregate. [11] The typical variable measured is the number of adopters, the emphasis is on the total market response rather than on an individual customer.

Diffusion models can be used to analyse two different situations. Figure 2 shows the difference between these. One point of view is to analyse one product market share and a new product adoption to replace the older one. The market size is fixed and the research question is at what rate will the new product generation replace the old one. Our case study will focus on the topic where a new product will be launched and the potential market size m is unknown. The two research questions here are to determine the potential market and analyse the rate of the diffusion process.

3.3 Qualitative Service Adoption Framework

One useful framework, which can be used to estimate qualitatively the speed of the service adoption and growth of the market demand is provided by the consultancy firm Constat [3]. A chart of the model is presented in Figure 3. This model splits the problem into five separate steps, which can be estimated separately. In this project the fundamental use of this service adoption framework is to provide realistic boundaries for the diffusion model in a case where no time series data exist.

Each phase of the framework may be analysed separately and in the overall analysis we can compare the factors which promote and demote the technology or service adoption.

“Catalysts” include two main groups, Marketing and Communication, i.e. how much the parties building the new technology will actively promote the new opportunities and Environmental catalysts such as influence of opinion leaders, peer pressure and so on. Diffusion models discussed earlier assume mainly “word of mouth” as a main mechanism. There seems to be strong connection with diffusion models and environmental catalysts on Constat framework. Communication and marketing effort include e.g. advertisement in mass media. But in today’s converging digital world it is possible to blur the borderline and provide tools to customers, which enable them to make part of the marketing effort by strongly enhancing word-of-mouth by super distribution tools such as messaging (including forwarding software based applications) and electrical discussion forums, chat rooms.

“Adoption DNA” is assumed to be something, which is strongly internal for each individual but by understanding these elements better it is possible to create approaches, which utilise the built-in factors of the potential buyers. This is often related to the differences between the early adopters, mainstream consumers and laggards, i.e. in the early phase it is more beneficial to try to impact the early adopters but the mass market will never materialise if the main stream consumers are ignored.

Constat uses four factors to characterise adoption DNA: Social system related factors, Brand relation factors, Knowledge based factors and factors dealing with Technology orientation of the people. These factors behave like filters to environment catalysts and communication and marketing efforts. As an example of knowledge based filtering factor is “Proven Use case”, which may be used to significantly increase the awareness of the new service. This helps ordinary people become aware of the new service faster than when they have to understand the new service without any earlier experience. The social system (workplace, friend, family, ...), where the potential buyer is normally, impacts awareness building but this area depends on the overall society. Therefore it can be assumed to be independent of the technology proposed in general and therefore this factor can be dealt by analogies in a diffusion model. Brand relations are important to in-

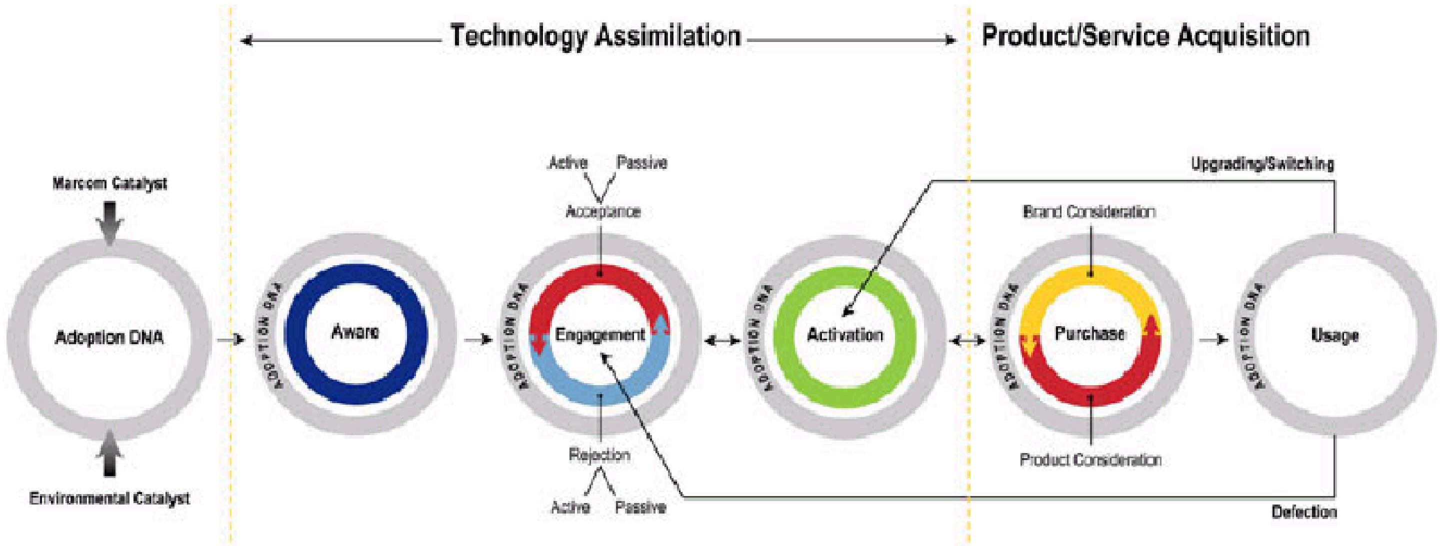


Figure 3: Service (and technology) adoption framework. [3]

crease credibility of the messages and in this way to increase awareness. Strong, already recognised, brands (well known companies) are quite important elements in awareness building. Finally the technology orientation of the potential buyers will filter (or amplify) the input signals in this process, but again, this can be considered as given for each nation and it will change only slowly with the general trend of raising level of education.

Step 1: Aware. Awareness of the potential end users is hence the result of the impact of catalysts through the internal assessment process of each individual. There probably is nothing in awareness building of DVB-H, which is likely to become a show stopper. But diffusion of the new service may be facilitated by various factors, which increase the awareness of the general public about this new service. Also if all the factors influencing awareness are ignored it is possible that no diffusion ever gets started. One environmental catalyst is also the integration of the DVB-H functionality to another mass-market consumer good, the cellular phone. This makes the users of the equipment show the devices to their peers more often than they would do in another case. Also the involvement of a large number of recognised companies in the value system will boost the awareness building significantly. In order to lower the threshold for mainstream consumers a proven use case, such as providing ordinary TV programs through this new media, would obviously be a major opportunity.

Step 2: Engagement. In engagement phase the end users may have four different reactions, active or passive acceptance or rejection. Those who most likely have immediate active acceptance include early adopters of technologies and respectively those who most likely actively reject the new service or technology are the laggards. Even if the groups may feel static, it is important to recognise that there are several factors impacting the reactions in this phase. Also this phase is not simply a one time event but one person may go through the engagement phase several times before the adoption moves to the next phase.

The factors, which influence the individual reactions in the engagement phase, depend on the service and product concepts. A first impression is very important and it is severely impacted by the usability and availability of the service (e.g. technical suitability and number of the services available and coverage of the network). Also the time (latency) to start the service, number of complex key sequences (in this phase there is no learning yet) as well as quality of the service compared to other similar services are important this is phase. In simple words, in engagement phase the service and the products have to support the primary purpose as well as possible.

Step 3: Activation. In Activation phase the end user is considering actively positive and negative points of the technology. Also she is looking for additional information either from the company providing the service or within her social framework. In activation phase it is likely that some kind of test service is used. The test service and test products should be available at very low cost or at no cost at all. Testing DVB-H service is not very easy, because it always requires dedicated new hardware to be available. It would be ideal if DVB-H service could be tested using standard DVB-T receivers, for instance. The lack of testing and trial opportunities shall be compensated by easy access to information about the service and also by binding the new service to existing service, i.e. by offering some popular TV and radio broadcast services also in the new media.

Step 4: Purchase. Purchasing decision is very important. Therefore the factors especially prohibiting easy, convenient and low risk decision shall be analysed. It is important that the service and the product (end user terminal) may be bought either separately or as bundled package. There are two customer groups, those who already have cellular subscription and only want to upgrade their mobile product and those who want to activate new cellular service at the same time. It is important that the end user do not have to buy expensive service packages directly in this phase. The strength of DVB-H concept is that several consecutive purchasing decisions can be done using the interactive mechanisms of the concept. Some start up package must be available with the initial purchase of the end user device. It is assumed that no separate TV license activation is needed in this phase but some existing TV license can cover the basic TV service for DVB-H too. To listen the radio channels there is no license anyway needed in Finland. Purchase decision involves comparison to competing product offerings. For DVB-H case the competing services include separate portable TV and portable phone combination but also stand-alone cellular phone with enhanced data capabilities may be considered as a competing solution. The price level of the total product and service concept has to be competitive. End users have to feel that the value for money is better in the DVB-H concept that in any of the competitors. Recognised brands will reduce the level of risk in the purchasing action. Risks can be reduced also by some other dedicated means.

Step 5: Usage. The smart idea in DVB-H concept is the interactivity between the end user and the service providers, both cellular and broadcast. This enables continuous possibility to upgrade the service and segment the market with the growing number of new users. However, in order to make this happen, the end users must be satisfied with the products and services also during longer period of time. Users will also use the service and products in many ways that were not even considered possible when the service was initially planned. End users want to integrate the service into their other similar services. Therefore a successful integration of cellular and broadcast features will provide high additional value in the DVB-H concept. This integration should not only cover the IP datacast features and functions but should go beyond and exploit the new concept holistically. These opportunities are discussed more in section 5.3.

The service adoption qualitative framework may be used in different ways. It may be possible to scale the diffusion model by the factors of the service adoption framework assuming that the analogies used to create the diffusion models represent some kind of average service adoption. If however more details are available on the service adoption characteristics of the analogies, it may be possible also to approximate the influence of these factors and find better estimate than just an average value. This type of study goes beyond the goals of this project.

4 Modelling and Forecasting Market Demand

The Bass model

$$\frac{f(t)}{1-F(t)} = p + qF(t) \tag{2}$$

is a differential equation, for

$$\frac{\partial F(t)}{\partial t} = f(t). \tag{3}$$

$F(t)$ can be solved and it has the solution [1]

$$F(t) = \frac{q - pe^{-(t+C)(p+q)}}{q(1 + e^{-(t+C)(p+q)})}. \tag{4}$$

Since $F(0) = 0$, the integration constant may be evaluated:

$$-C = \frac{1}{p+q} \ln \frac{q}{p} \tag{5}$$

and

$$F(t) = \frac{1 - e^{-(p+q)t}}{\frac{q}{p} e^{-(p+q)t} + 1}. \tag{6}$$

This model is linked to the real world through the parameter m, the final cumulative level of adoption.

$$N(t) = mF(t) \tag{7}$$

is the real world number of adopters given by the model. The estimation of m can be done by fitting the data to the model, but being able to estimate m by some other means will leave more degrees of freedom to estimate of p and q.

Since no prior data on DVB-H device sales exists, it is not possible to fit the model into data. When no data are available, parameter estimates can be obtained by using management judgement or the diffusion history of analogous products [11]. Lawrence's and Lawton's [10][1] study of several products lead them to suggest using $p+q = 0.00137$. That recommendation is very general and better results are gained, according to Thomas [20][2], by calculating the parameters from a weighted sum of the parameters of analogous products.

We will estimate the parameters of DVB-H sales by using the analogies of DIRECTV and Sony Walkman. DIRECTV is a satellite TV service launched 1994 in the USA [2]. Today they offer more than 225 channels and pay per view services. DIRECTV is a good analogy for an increase in the number of services offered. We assume that DVB-H is to DVB-T what DIRECTV was to CTV (cable television). Sony Walkman is a portable cassette player launched 1979. It came out at a time when people had stereos at home, but they could not listen to their favourite music when they were on the move. The Walkman enabled mobility, just like DVB-H enables mobility when compared to ordinary television.

Estimating a diffusion model's parameters from data is a matter widely discussed in literature. Bass himself suggested an ordinary least squares (OLS) procedure which involves the discretisation of the model [1]. Rearrangement of (1) and substitution of (7) yields

$$\begin{aligned} N(t_i) - N(t_{i-1}) &= pm + (q-p)N(t_{i-1}) - \frac{q}{m}N^2(t_{i-1}) \\ n(t_i) &= \beta_1 + \beta_2 N(t_{i-1}) + \beta_3 N^2(t_{i-1}), \end{aligned} \tag{8}$$

where $\beta_1 = pm$, $\beta_2 = q - p$ and $\beta_3 = -q/m$. Linear regression analysis is used to estimate $\vec{\beta}$. Once $\vec{\beta}$ is known, p, q and m can be calculated. This method however has shortcomings that include not providing standard errors for the estimated parameters p, q and m [15][3]. Schmittlein and Mahajan [15] have suggested a maximum likelihood estimation procedure to estimate the parameters directly from (6). This procedure also has its limitations. [11]

Srinivasan and Mason [18][4] have suggested that p, q and m should be estimated using nonlinear regression. That is what we will set out to do. The idea is to find the parameters

$$\vec{\theta} = \begin{bmatrix} p \\ q \\ m \end{bmatrix} \tag{9}$$

[1] Cited in [11].
[2] Cited in [11].
[3] Cited in [11].
[4] Cited in [11].

that minimise the sum

$$\sum e_i^2 = \sum \left(y(t_i) - \hat{y}(t_i|\vec{\theta})\right)^2 \tag{10}$$

where $\hat{y}(t_i|\vec{\theta})$ is the estimate of $y(t_i)$ as given by the model (6) with parameters $\vec{\theta}$. The model is nonlinear and therefore this problem is not linear. The solution is found using Matlab's function `fminsearch`. The Matlab-code used for estimating the parameters is in five .m-files. The files are presented in Appendix 3.

`etsidirect.m` and `etsiwm.m` are used to find the parameters of DIRECTV's and Walkman's diffusion models. They use `fminsearch` to minimise either `residual.m` or `residualm.m` depending on whether m is given or if it has to be estimated from the data.

There is no exact distribution theory for the parameters of nonlinear models. Usually, when there are lots of observations, the parameters $\hat{\vec{\theta}}$ follow a normal distribution. Srinivasan and Mason use this approximation in estimating the parameters for consumer durables even though they have only as few as eight observations [18]. Using asymptotic approximations, confidence intervals for the estimated parameters are found by calculating the Jacobian of the target function [7]

$$N(t) = mF(t). \tag{11}$$

The Jacobian is evaluated at all observation points.

$$\mathbf{J} = \begin{bmatrix} \frac{\partial N(t_1)}{\partial p} & \frac{\partial N(t_1)}{\partial q} & \frac{\partial N(t_1)}{\partial m} \\ \frac{\partial N(t_2)}{\partial p} & \frac{\partial N(t_2)}{\partial q} & \frac{\partial N(t_2)}{\partial m} \\ & \vdots & \\ \frac{\partial N(t_n)}{\partial p} & \frac{\partial N(t_n)}{\partial q} & \frac{\partial N(t_n)}{\partial m} \end{bmatrix} \tag{12}$$

The covariance matrix of the parameters is given by

$$(\mathbf{J}^{\mathrm{T}}\mathbf{J})^{-1}\mathrm{MSE}, \tag{13}$$

where $\mathrm{MSE} = \mathrm{SSE}/(n-l)$ is the mean sum error[5] [7]. n is the number of observations and l is the number of parameters estimated from data. Because m is much bigger than p and q it is necessary to use scaling. Otherwise the $\mathbf{J}^{\mathrm{T}}\mathbf{J}$ runs the risk of being singular and then it would not have an inverse. Scaling is done by dividing $\partial N(t_i)/\partial\theta_j$ by m in the case of $j = 1$ or 2 (corresponding to p and q). This transforms the partial derivative $\partial N(t)/\partial t$ effectively into

$$\frac{\partial F(t_i)}{\partial \theta_j}. \tag{14}$$

[5] SSE = sum squared error = $\sum e_i^2 = \sum \left(y(t_i) - \hat{y}(t_i|th\vec{e}ta)\right)^2$.

Then

$$\mathbf{J}' = \begin{bmatrix} \frac{\partial F(t_1)}{\partial p} & \frac{\partial F(t_1)}{\partial q} & \frac{\partial N(t_1)}{\partial m} \\ \frac{\partial F(t_2)}{\partial p} & \frac{\partial F(t_2)}{\partial q} & \frac{\partial F(t_2)}{\partial m} \\ & \vdots & \\ \frac{\partial F(t_n)}{\partial p} & \frac{\partial F(t_n)}{\partial q} & \frac{\partial N(t_n)}{\partial m} \end{bmatrix}, \tag{15}$$

where

$$\frac{\partial F(t)}{\partial p} = \frac{\frac{q}{p}e^{-(p+q)t}\left(-\frac{1}{p}e^{-(p+q)t} + t + \frac{1}{p} + \frac{tp}{q}\right)}{\left(\frac{q}{p}e^{-(p+q)t} + 1\right)^2} \tag{16}$$

$$\frac{\partial F(t)}{\partial q} = \frac{\frac{1}{p}e^{-(p+q)t}\left(tqe^{-(p+q)t} + tp - 1 + tq + e^{-(p+q)t} - tqe^{-(p+q)t}\right)}{\left(\frac{q}{p}e^{-(p+q)t} + 1\right)^2} \tag{17}$$

$$\frac{\partial N(t)}{\partial m} = F(t) = \frac{1 - e^{-1(p+q)t}}{\frac{q}{p}e^{-(p+q)t} + 1} \tag{18}$$

4.1 DIRECTV

Subscription data of DIRECTV has been found from 1994 to 2002 [2, 14]. For the year 2002 we have found monthly data. For the other years data is yearly. Quarterly predictions also exist for the year 2003, but they have not been used in our estimation of the parameters. Bass et al. have estimated that DIRECTV will be adopted in 16 % of TV-households in the USA [2]. According to Nielsen Media Research there were 108 million TV-households in the USA in 2003 [4]. This gives

$$m_d = 0.16 \cdot 108.4\text{E6} = 17.34\text{E6}.$$

Fitting the model to the data using the estimated value $m = m_d$ results in the parameters $p_d = 7.79\text{E-5}$ and $q_d = 9.21\text{E-4}$. If m is estimated from the data, then $m_d = 12.8\text{E6}$, $p_d = 5.75\text{E-5}$ and $q_d = 1.60\text{E-3}$. A plot of the data and of the model using these two different sets of parameters is presented in Figure 4.

The covariance matrix is, when m_d is given as 17.3 million,

$$\begin{bmatrix} 7.72\text{E-11} & -4.24\text{E-11} & -4.29\text{E-7} \\ -4.24\text{E-11} & 5.70\text{E-8} & -4.82\text{E-5} \\ -4.29\text{E-7} & -4.82\text{E-5} & 0.0436 \end{bmatrix},$$

which yields

$$\hat{s}_p = 8.78\text{E-6}$$
$$\hat{s}_q = 2.39\text{E-4}.$$

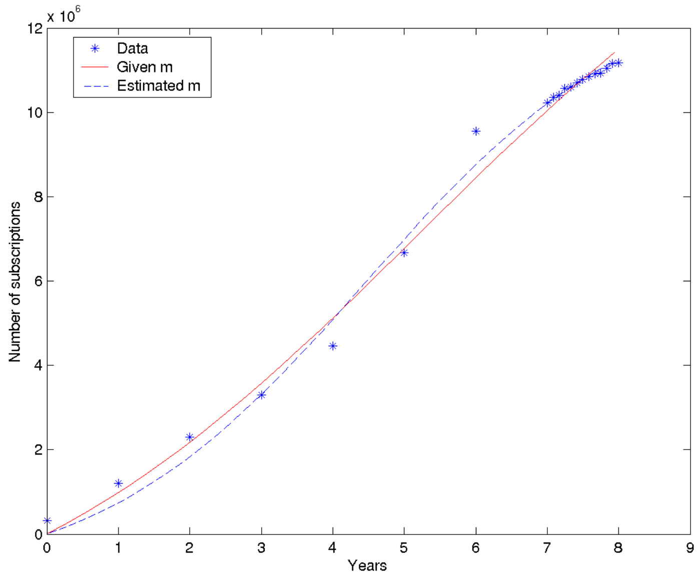


Figure 4: Cumulative subscriptions of DIRECTV.

In the case where m_d is estimated from the data, the covariance matrix becomes

$$\begin{bmatrix} 7.97\text{E-}11 & -1.34\text{E-}9 & 2.82\text{E-}7 \\ -1.34\text{E-}9 & 2.75\text{E-}8 & -6.78\text{E-}6 \\ 2.82\text{E-}7 & -6.78\text{E-}6 & 1.90\text{E-}3 \end{bmatrix},$$

which yields

$$\hat{s}_p = 8.93\text{E-}6$$
$$\hat{s}_q = 1.66\text{E-}4$$
$$\hat{s}_m = 0.0437.$$

4.2 Walkman

Walkman data is available from 1979 to 1998 (see App. 2) [17]. The sales numbers are for the whole world. Fitting of the diffusion model to the Walkman data leads to the following parameters $m_w = 214\text{E}6$, $p_w = 1.81\text{E-}5$ and $q_w = 7.56\text{E-}4$. The actual data and the model are plotted in Figure 5.

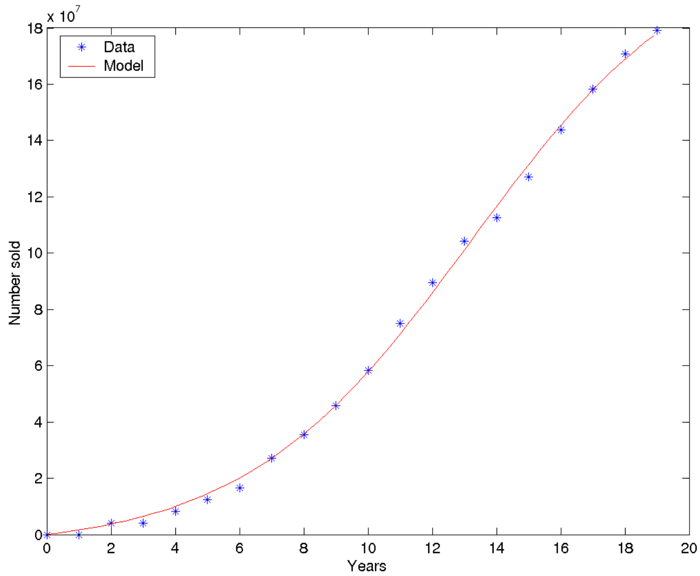


Figure 5: Cumulative sales of Walkman.

The covariance matrix is

$$\begin{bmatrix} 2.67\text{E-11} & -6.61\text{E-10} & 3.87\text{E-7} \\ -6.61\text{E-10} & 2.19\text{E-8} & -1.73\text{E-5} \\ 3.87\text{E-7} & -1.73\text{E-5} & 0.0171 \end{bmatrix},$$

which yields

$$\begin{aligned} \hat{s}_p &= 5.17\text{E-6} \\ \hat{s}_q &= 1.48\text{E-4} \\ \hat{s}_m &= 0.131. \end{aligned}$$

4.3 DVB-H

The parameters for the DVB-H are estimated from the parameters of the two analogies. Walkman represents mobility and DIRECTV the proliferation of services. Since we have no reason to do otherwise, we will give both of the analogies the weight $\omega_i = 0.5$. We use the parameter estimates of DIRECTV that are found using Bass et al.'s estimate of 16.3 million for m in calculating the estimates for DVB-H.

Assuming uncorrelated random variables the expectation value of the weighted sum of random variables is the weighted sum of the expectation values of the variables. The variance of the weighted sum of random variables is the sum of the variances of the variables weighted with the squares of the weights. [8]

$$\mathrm{E}\left(\sum \omega_i x_i\right) = \sum \omega_i \mathrm{E}\left(x_i\right) \tag{19}$$

$$\mathrm{Var}\left(\sum \omega_i x_i\right) = \sum \omega_i^2 \mathrm{Var}\left(x_i\right) \tag{20}$$

These yield the parameter estimates

$$\hat{p} \sim \mathrm{N}\left(4.80\text{E-5}, (5.10\text{E-6})^2\right)$$
$$\hat{q} \sim \mathrm{N}\left(8.38\text{E-4}, (1.40\text{E-4})^2\right).$$

Service Adoption in Segments

It is possible to analyse different segments of the Finnish population separately to estimate their final cumulative levels of adoption. An extensive study was made during 2003 by Caj Södergård et al. [19]. The conclusions in this study indicate that there are two main groups of strong acceptance: Children between 0–12 years and adults between 41–50. The first group (children) used the Mobile TV to simply watch ordinary TV privately. The adult group used the TV in the mornings and during breaks to check some news and watch programs they seldom watch with normal TV because of the time and place limitations. Young adults and teenagers were surprisingly less interested in this opportunity. This study was done using devices and a network with limited performance. This may have some impact to people who already are used to other portable devices with many development cycles and mature technologies. Therefore the implications of this research should be dealt with concern. [19]

When comparing the results of the Södergård study with Moore's customer segmentation it seems that the study is dealing with early adopters, who like to test any new service or device and early mainstream customers, who are willing to adopt a new service when it provides a clear solid use case, which is useful for them. Volunteers for the research were searched using emails and newspaper advertisements. Therefore they most likely all belong to the first 3 groups identified by Moore. [12]

It seems that candidates to purchase the device and the service include:

1. Technology enthusiasts and visionaries, 10 % of the population. They may belong to any of the following groups, but most likely to group 3.

2. Children and their parents, One device for whole family use (like just another TV set), 100 % of families with children. There are some 600,000 families with children in Finland, which as number of families can be converted as 12 % of the overall population. Note, that in these families live total about 2.18 million people, representing 42 % of the total population.

3. Teenagers and young adults who are upgrading their earlier (multimedia oriented) cellular mobile devices. Ultimately 100 % penetration of the current users may be achieved. These people will definitely have the product and the service for their personal use. There are 1,660,000 people in this group, consisting of 32 % of the total penetration

4. The rest, which are not included in the previous groups. 100 % penetration per household. This consists of singles and adult couples and others. We can simply calculate $100 - 42 - 32 = 26$ %. Group 1 should not be taken into account here, because they may be in any population group. Divorced and widows represent 14 % of the total population, hence we may assume that this group consists of $12 + 14/2 = 19$ % worth potential customers.

The population statistics are courtesy of Tilastokeskus 2004 [21]. Naturally the overall estimation is very rough, but may give some estimate for the total maximum potential customer base: Case2 + Case3 (including Case1) + Case4 = $12 + 32 + 19 = 63$ % of the population. This estimation is based on very limited trial and very limited number of people. Nevertheless, it is the best estimate available until a more precise market study is undertaken.

We will assume that the coverage area will not be the whole of Finland at the beginning. Instead, coverage will be built as the service is adopted by more people. At the beginning the coverage are will include major cities. Then it will be expanded to smaller cities and along main highways and railroads. Finally by the year 2013, we assume that the coverage area will be 95 % of the population and 70 % of the surface area in Finland.

Since this is a study of a mobile service we assume that people will want to enjoy the mobility. If the surface area coverage is not big enough customers will become disillusioned and they will not acquire the service. We will assume that 90 % of the Finnish population ($0.9 \cdot 5.21\text{E}6$) lives and moves in an area with coverage [21]. Therefore we have $m = 0.90 \cdot 0.63 \cdot 5.21\text{E}6 = 2.95$ million. This assumes that early adopters are mostly young adults and teenagers. It sounds like a reasonable assumption and the size of the early adopters is 10 % of the population. Therefore, we assign $m \sim \text{N}\left(2.95\text{E}6, (7.53\text{E}4)^2\right)$, which is equivalent to saying that the 95 % confidence interval is ±5 %.

5 Mobile Broadcast Service and Value System

Mobile Broadcast service and related Value system is a combination of two existing services and value chains, Broadcast and Mobile Cellular. It is not only that these two value chains have to co-exist but a rather deep integration of technologies, applications and services is needed. In best case the total value created by this new concept may be significantly more than the sum of the parts but in worst case it is possible that push by the market players is not co-ordinated at all and may hence result a vector sum near to zero.

The deep integration of the two paradigms has been taken as a starting point in this research. The full integration has been assumed in all areas, because nothing less will bring the benefits to the end users. Partial integration would have resulted much more difficult and cumbersome end user usage models. The full integration means for instance that the same content is available through both value chains in principle. It is also assumed that the network will automatically select the chain, which is more efficient and cheaper in case both are available. Similarly it is assumed that all terminal devices are dual mode, cellular transmission and broadcast reception capable. These assumptions have made it possible to keep the market non fragmented and no separate forecasts are needed for areas where broadcast coverage is poor until 2007 because of limitations of the broadcast spectrum. Only fundamental technical limitations, such as missing uplink of broadcast chain, will limit the dualism.

5.1 Services and Applications

There are many ways to categorise the services. Kivisaari and Luukkainen have proposed a very useful model for basic DVB (ie. fixed digital broadcast) [5].This classification includes six main classes: Program guides, Information Services, Communication Services, Entertainment, Transaction services and other services, e.g. application downloading and also voting. The same classification can be used to model mobile services. The importance of each service and service category as well as users' behaviour in mobile environment is partially different but it is important to note that DVB-T services can be used only while not mobile.

Application in this research project means primarily the software application in the mobile device, which implicitly includes also the related functionality in the network servers. Application is the entity, which interfaces the end user to the service. One application may be used with several services. (Streamer client used to listen music and watch movies and movie clips.)

When the overall value system is analysed there are also other services, which may be crucial for fast service adoption. These include providing proper settings for the end user devices, providing charging and billing of the service charges and other services the end user might need, e.g. help desk.

5.2 Value System

The overall value system is a combination of broadcast and mobile cellular value systems with additional elements, which provide the integration functionalities of these two chains.

Primary Value System

The primary role in the value system is in the service delivery layer. The Service delivery layer is assumed to be the primary interface to the end user in both paradigms. The role of network layer in both contributing value chains is simply to deliver the bits and inform the respected bit pipe charges to the service delivery layer. Similarly the content provisioning has limited access (if any) to end user but the service agreements are handled by the service delivery layer. Therefore the critical interface, which must work efficiently, is the interface between the two service delivery layer elements in each value chain, the Mobile Service Operator and the Broadcast Service Operator.

In Finland regulation has prohibited the bundling of cellular terminals and cellular service. This regime is expected to continue also in the case of DVB-H. Therefore the independent retailing of end user devices is assumed in the value system. Retailing of the devices is logically part of the service delivery layer. Terminal device and infrastructure vendors in this model are seen as a separate layer. Depending on the service portfolio, it may be that consumer electronics distribution is stronger candidate that mobile operators' distribution channel also to take care of the retail and service responsibility of the end user devices.

The value system analysis may be simplified by assuming that for most of the players the value system is the same or very similar to the existing value chain they already participate, except for the cellular and broadcast service operators. They have to build new interface towards each other. Taking into account the history of broadcasting and cellular telephone businesses it is obvious that these two parties may as well consider each other as potential competitors, not necessarily as partners.

For the broadcast operator it is possible to implement the broadcast part of the service without any support from the cellular service operator. This approach does

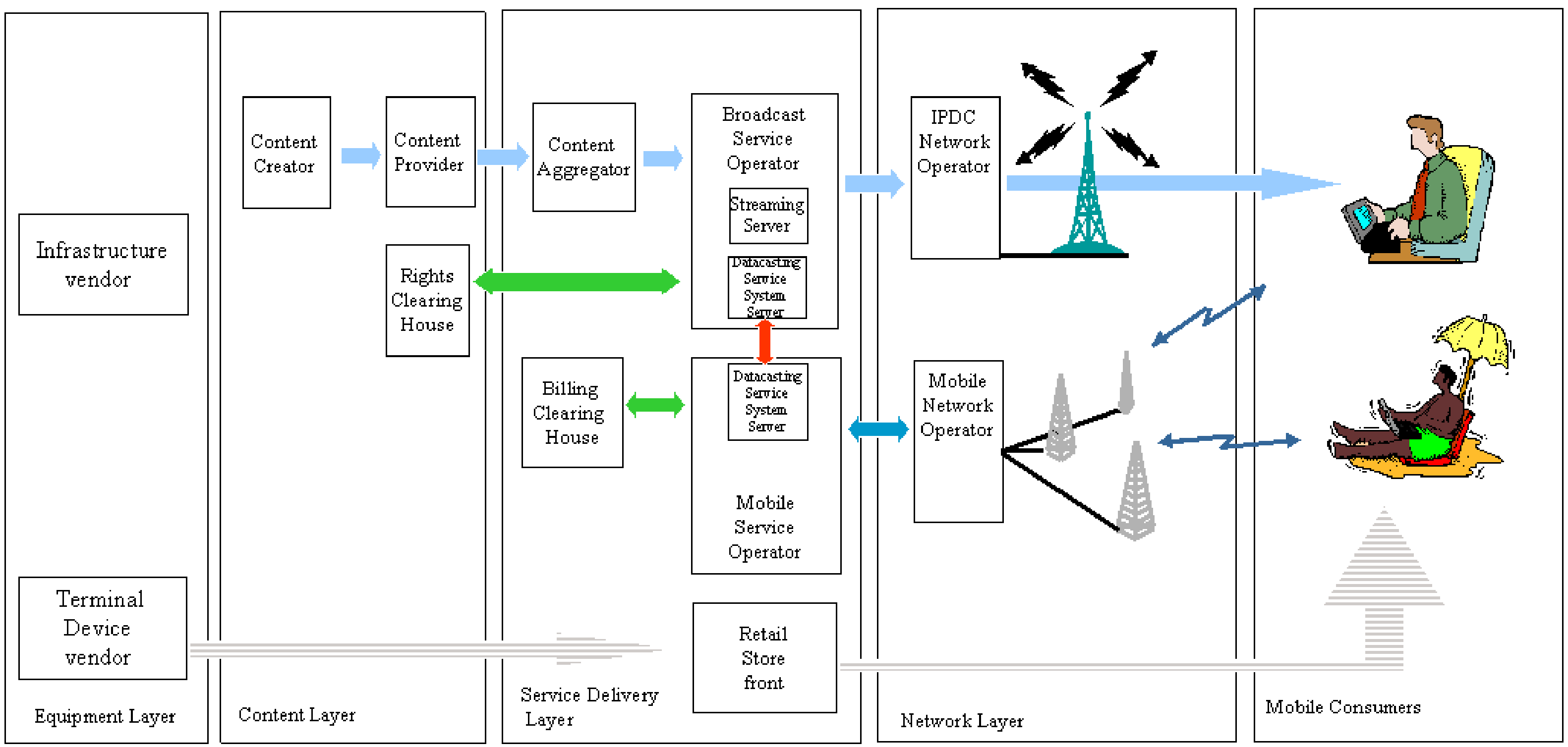


Figure 6: Overall value system.

not however have any feedback path, uplink, and therefore only limited set of services, those, which do not require real time interactivity, can be implemented. It is possible to manage the customers and their service set based on some smart cards but this will require expensive and inconvenient in-person management process to be set up. Many of the important aspects of service adoption discussed in section 3.3 will be jeopardized.

For the cellular operator it is possible to extend the service they currently have with data streaming and downloading. Providing continuous bit stream, as needed for e.g. TV transmission, is economically impossible even with 3rd generation cellular technologies in large scale.

The principal question is, which player should own the customer? Currently the largest customer base (among the relevant potential players within these value systems) is with cellular operators. The customer base of the TV broadcasters is large but since the customer registers are not managed by them but the regulator, it may considered as low opportunity for the broadcasting company. Also the complex and expensive charging and billing systems already available for cellular service operators can be extended and re-used with low additional effort. Probably the most important factor is that the customers already are accustomed to pay bills through the cellular operator for value added services, such as ring tones and parking charges. Because of the complexity of the new service, good itemised billing is needed. Otherwise there may be negative impacts to the basic voice service use, if the end users do not recognise the IP Datacast expenses separately from ordinary telecommunication charges. It is an open question how the feedback channel data charges should be handled, either bundled with other data charges or built into the service bundle of IP Datacast.

As a conclusion it looks realistic that cellular service provider is running the servers, which manage the interactive actions by the end user. The forward channel, its multiplexing should be managed by the broadcast operator. It is important to recognise further that anybody should be able to run value added services, including naturally cellular and IP datacast service operators, but also anybody who is willing to set up such services. The proliferation of the service portfolio is one of the critical success factors of the service adoption.

For the success of the system it is fundamental that all relevant and required elements of the value system exist, are able to invest and will receive adequate return of their investment. This aspect is very important to implement differently from earlier wireless service concepts, such as WAP, where the cellular network operators in many cases have overestimated the value of transport over the content. A good example can be seen in Japan, where network operator has decided to collect only 9 % commission of the service revenues, which is comparable to the

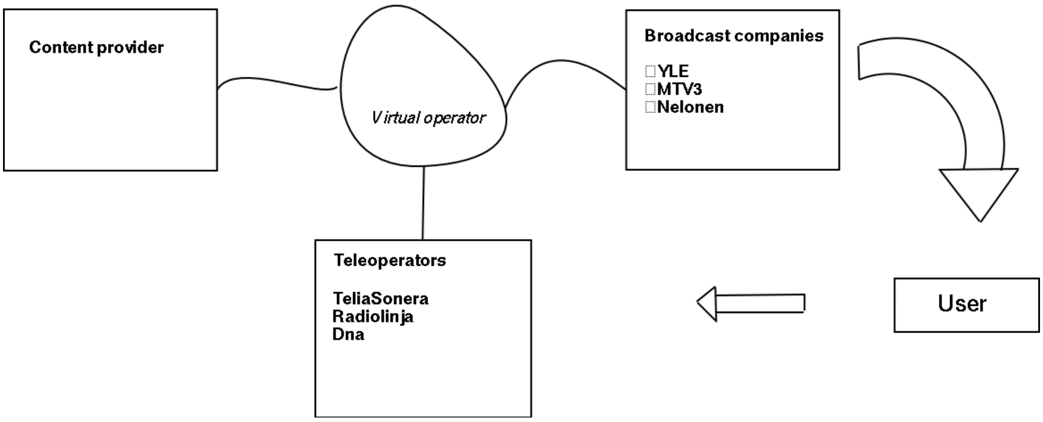


Figure 7: Key players in the Finnish industry.

additional workload and responsibility for the operator due to the operation of the charging and billing system for the benefit of the service providers. Network operator, however, will collect 100 % of the transport charges. This allows 3rd parties to succeed also in the value system. This is a special challenge in this current concept, because there are actually two service operators and two transport operators, which all may overdo their role as gatekeeper for the 3rd party service and content providers.

Since market demand of any service is depending on the previous success of the service, it cannot be forecasted without taking the value system elements fully into account. Any one of the players of the value system is able to destroy the potential overall positive business case of IP Datacast.

The players in Finland in the Value Chain are likely to be as follows, presented in Figure 7. There are numerous content creators. Multiple minor groups (bands, film groups) create content and offer it to content provider. These groups/companies are likely to be content specific and hence their detailed identification serves no purpose nor is possible. Content providers sell their content packages to actual content houses like radio channels, MTV3 and YLE, for example. Their job here is to create a set of content originating from numerous sources and form it into a package with market momentum. Digita is the builder of the test network that becomes operational in the latter half of 2004. It is also one of the possible constructors of the final IPDC network. It might request some participation from mobile operators (TeliaSonera, Elisa, dna).

Another View: Business Applications Value System

The primary value system discussed above is totally consumer oriented. It should be noted that most of the fast growing business have first gained acceptance in business domain rather than consumer domain. It goes beyond the scope of this project to analyse in detail what it would mean to the service adoption rate if another parallel value system would be build for business use.

Using exactly the same technical components as in the primary value system a dedicated service for business use can be built. Some of the business services may be based on downlink channel only, some would benefit from the parallel duplex cellular channel.

Examples of Business oriented services
Mobile TV for metropolitan area public transportation. This system would distribute relevant real time information for all the buses and trains. Local software would select the most relevant information for any particular bus or train. This could also cover the busstops and railway stations. Examples of such relevant information include time tables, special event along the route of the bus etc. The advantage is the low cost devices and transmission. Interactivity may not be needed in the first phase but in later phase could be used to e.g. browse some special information, which is not reasonable to be transmitted continuously to all receivers. Most likely it would be enough to allocate some part of one of the channels to buses. Mobile TV on buses may also show news and other timely information as a video stream. Mobile Public Transport TV could also be available for taxi cars and metro trains.

Another example might be bird-watching and similar groups of people, who might be interested in “text and multimedia paging” type service. Using IPDC this service could be created at very low transport cost.

5.3 Technology opportunities and limitations

There have been many previous attempts to provide interactive multimedia using either broadcast or telecom technologies or even combinations of the two. One of them is used in this study as a reference analogy for the service adoption. In order to understand the current research case better it is important to review the strengths and weaknesses of the current technology proposal versus the early available systems.

Because the IP Datacast concept is fundamentally a combination of two originally independent concepts there are strengths and weaknesses, of which some are specific for the independent systems, DVB-H and 3G and others to their combination.

The main advantages, which the DVB-H includes over traditional DVB-T, are new radio modulation and multiplexing, which allows reception of the signal even in noisy environment, both indoors and with high mobility. Also the enhanced technology include power saving features, especially sleeping periods between desired transmissions. Also the content optimization for portable devices will facilitate the personal use of the DVB handheld devices.

Cellular mobile technologies are developing further and there are some specific advantages in 3G over traditional 2G GSM. The main advantages include a possibility to clearly higher bit rate, at least 384 kb/s downlink speed, which is comparable to one multiplexed DVB-H channel.

When we look at the 3G technologies, WCDMA is clearly able to support as high bitrates as needed in IPDC. The challenge with WCDMA is that its cell radius is relatively short and therefore the coverage will be limited also. This is because of quite low emitted power of WCDMA terminals and base stations and also because of the high operating frequency range, aroung 2GHz. It may be that WCDMA will not be deployed outside of urban areas. Therefore it is important to look at the other alternative to build 3G coverage. GSM based EDGE (Enhanced Datarates for GSM evolution) can support bit rates up to 69.2 kb/s per time slot, i.e. up to 553.6 kb/s for the whole carrier. In practical networks it can be estimated that around 40 kb/s per time slot is achievable in average. GPRS class 19 terminals can be built without the burden of full duplex transceivers. These terminals use 6 timeslots downlink and therefore can support practical datarates up to 240 kb/s. One of the candidate 3G systems, UWC 136, in the USA is using EDGE technology. It is still a bit limited compared to the targets of IPDC. This disadvantage may be compensated by some additional memory of the device and typically immediate response of the GPRS network vs. waiting delay of programs in IPDC. The overall experience may not be different enough to bother the end user.

The end user portable terminals in 3G time frame will support significantly more complex computational requirements and better user interface capabilities, such as video and audio in/out, which enables the cost structure of such technologies to develop fast. Also the native full duplex connectivity with Internet will materialise in mobile cellular devices during the next few years.

The main promise of the combination concept in IP Datacast is to solve the issues, which still remain in each of the stand-alone concept. The main unique advantage of the combined broadcast/cellular technology is to provide low cost broadcasting downlink and reasonably fast cellular uplink. There are other very important advantages also. The possibility to use mobile cellular technology also as gap filler and relief the DVB-H network deployment from worst case network planning. Combined technology may also be used to download executable applications, which will require standard open execution platform, such as Symbian or JAVA, which already is available in mobile cellular devices. Application downloading will require independent service settings and parameters to be provisioned. Mobile Cellular devices will have solutions for this anyway. The same solution may be used but other solutions can be developed.

The fundamental question here is the dual mode operation for the user data. If cellular network is used to complement fully the patchy IPDC coverage, we do not need to scale the maximum potential customer base. If the dual mode operation is not enabled, then the available coverage shall be used to mark the potential customer base. It is not likely that people purchase devices and services if there is no coverage.

5.4 Coverage

There is a preliminary plan to bring the coverage up in Finland. These plans are still in the early phase. The final coverage will cover 95 % of the population, including major highways, roads and train connections. Nevertheless, we used only 90 % in section 4.3 to compensate for the gaps that hinder the mobility.

If dual mode operation can be used to complement holes in the coverage plan, no reduction in the maximum number of potential customers is needed. If however the dual mode operation is not enabled, we propose to use the coverage percentage directly as scaling factor. The schedule of deployment plan and its implications are not taken into account, since it seems that the current schedule is fast enough and the critical factor will be the maximum coverage.

5.5 Pricing

Pricing of new service is quite a critical process. The price must be balanced between the new value the service obviously has to provide and the price of existing services, which still can be competitive. Utility function of the consumers is normally a great mystery.

Service pricing

One way is simply to ask potential customers how much they would pay. Södergård did ask this question after the filed trial. Surprisingly high willingness to pay was recorded. But on the other hand the paying mechanisms were found difficult. The most likely successful case would be flat rate monthly tariff. This should cover the normal use paradigm. Special additional fees may be applicable to ad hoc usage in some special cases. Monthly charges should vary between 3 € and 50 € according to Södergård [19].

If we compare this to competing applications, such as normal TV licence (15.5 € per month), monthly flatrate of broadband access (35 €) , monthly bill of cable TV (6 €) or current GPRS block rate (18 €/100MB), those all fall between 6 to 35 € per month. It is difficult to believe that monthly spending would exceed these values significantly. If one program would cost something like 1 €, that would mean only 30 programs per month, ie. 1 program per day. This is clearly not acceptable to the primary group of early majority, i.e. the children and especially their parents.

Since the pricing of IPDC is totally open at the moment we cannot estimate its impact quantitatively but as a recommendation could be that the price level should stay within the monthly spending of comparable other media. We must assume that taking IPDC service in use would not substitute any existing service but rather become additional spending item for the users.

One example of potentially viable pricing scheme could be as follows

- Basic use
  - Normal TV service in mobile (all main channels of DVB-T),
  - Service provisioning using cellular access,
  - Basic GSM/GPRS service
  - Tariff proposal: Basic GSM/GPRS tariff, TV license if not already available
- Full Mobile use
  - Basic use plus:
  - Full Mobility (using GPRS/3G as fall back)
  - Pay per view possible
  - Tariff proposal: Basic + 20 € monthly bill, Pay per view comparable to price of similar content on CD/DVD
- Heavy User case may have completely different charging mechanisms.

Terminal pricing

Terminal pricing in Finland is currently separated from service pricing. This is a straigth forward way to analyse the case. If however some kind of bundling of service and terminals is planned, it may be assumed that terminal price is allocated to service price for the period of 2 to 3 years.

This seems to be the renewal cycle of portable devices. There is no real data available on the price level of the future IPDC terminals. We may assume that the starting price without any subsidies and with the same pricing models as today's cellular products, would be quite high, of the same order as the communicator products like Nokia 9210. The current price range is about 700-800 €. IPDC functionality has to be integrated, which will increase the price even further. This is far beyond the typical consumer product price range, around 250 €. We may assume simple price erosion of product performance (different from price erosion of actual products) based on Moore's law (performance is doubled every 18 months). This would indicate that IPDC terminals may reach consumer price range in $x = (\ln(1000) - \ln(200))/\ln(2) = 2$ periods, ie. In 36 months. This estimation is only for the CMOS performance, the overall product consists of many other elements. Also the actual products are not simply optimised in price but additional features and function are added in each product cycle. This reduces the price erosion of the end user products in the shops. But still it may be summarised that minimum performance IPDC terminal price could be in 3 years from the beginning of the consumer market, ie. 2009. Terminal prices depend very much on the production volumes. It is obvious that Finnish market alone is not able to bring down the prices. In this study we have assumed that there will be at least pan-European market of compatible products. This will also facilitate several manufacturers to provide these products, which will further push prices down with the competition. European-wide operation is possible because the both standards, DVB-H and GSM/GPRS/WCDMA will be recognised and European standards. It is actually very questionable to predict anything for IPDC service adoption in Finland without connecting this to the concurrent service adoption throughout Europe and preferably even larger market.

There are many research papers available about optimal pricing of the new service and products. One useful analysis, which is also possible to integrate to the basic diffusion model is by Krishnan, Bass and Jain [6]. They actually propose somewhat lower prices for the market entry and increasing the price with the diffusion until roughly inflection point, when the normal rules of market economy start bringing the prices down again. Lower price in the beginning would facilitate faster adoption of the new products and service.

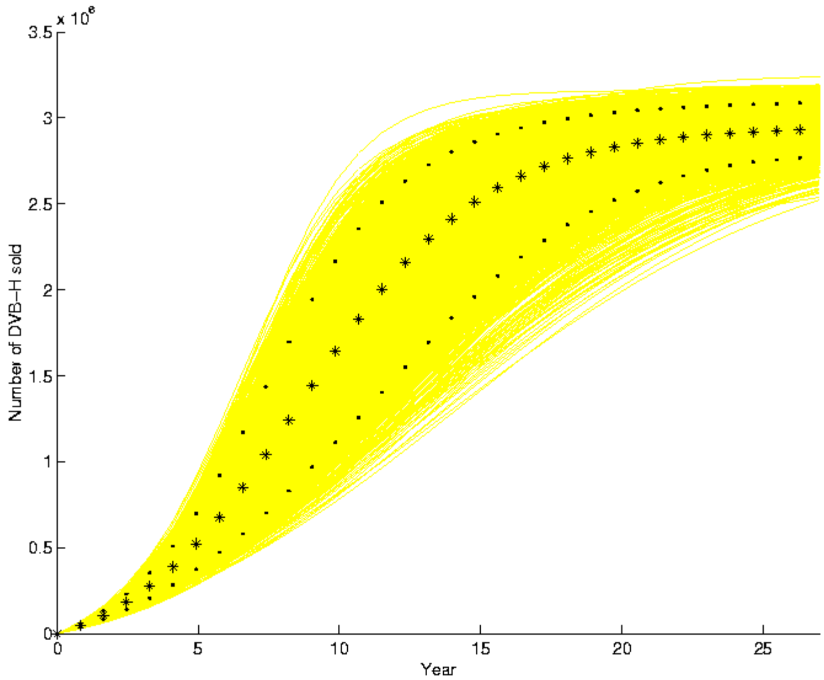


Figure 8: Forecast of DVB-H sales and it's 95 % confidence interval.

6 Monte Carlo

Monte Carlo simulation is a widely used methodology to solve problems that are not analytically tractable. We will use it to determine confidence intervals for the forecast. Monte Carlo simulation suits our purposes well because the model is nonlinear and the parameters are assumed to be constant over time [9]. The simulations were carried out using MATLAB.

The forecast is calculated as the mean of all the simulated curves and its confidence interval is calculated from the 2.5 % and 97.5 % percentiles. This means that 95 % of the outcomes lie between the confidence interval. The forecast simulated with 10,000 repetitions is presented in Figure 8. Each curve in the Figure is a realisation of certain parameters p, q and m. The parameters were independently sampled from normal distributions. The parameters of the normal distributions are presented in Table 1. Their derivation is presented earlier in this report in section 4.

The result of the simulation shows that there is considerable deviation in the rate of diffusion. The service provider or operator is not as such restricted by limitations in the rate of supply, and can thus concentrate on evaluating the lower confidence

Table 1: The parameters of p's, q's and m's distributions.

	p	q	m
mean	4.80E-5	8.38E-4	2.95E6
s.d.	5.10E-6	1.40E-4	7.53E4

interval of the forecast. Quite a few of the worst cases of diffusion lie underneath the lower confidence interval. The diffusion is not diverted as far higher up as down. It means that the maximum possible outcome is closer to the average than the minimum. This forms a certain risk to the stake-holders. There is a possibility for major losses if the weakest simulated outcome realises. On the other hand the best simulated outcome does not run much higher than the average, even though the differences are significant.

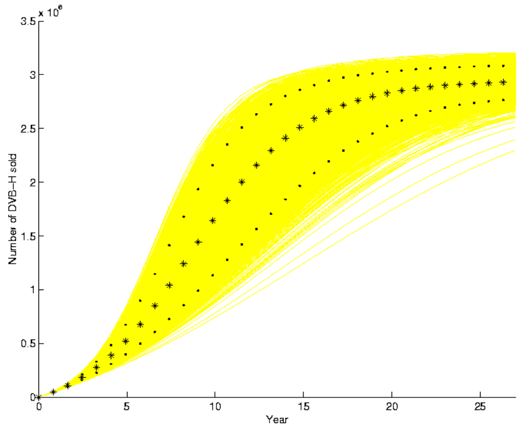
According to the forecast, a cumulative adoption level of 10 % will be achieved in 3.3 years. A cumulative adoption level of 90 % is achieved after 16.4 years. The inflection point is found at 8.8 years. During year 8 aproximately 250,000 new subscribers will adopt DVB-H. That is also the time when the forecast is most inaccurate.

Although it is assumed that there is no uncertainty in time, the simulation results can be analysed within the time-frame. From Figure 8 it can be estimated that in extreme cases, the first 500,000 units are sold somewhere between the four and seven years from the launch of the product. Further on, the time frame only expands so that with one million units the time frame is 3 years ranging from 6 to 9 years. For 1.5 million units the time frame is over 5 years ranging from 7 to almost 13 years. Respectively, for 2 million units it is over 6 years with a range from 9 to 15 years. From a company's point of view such time frames complicate the situation even more. There is significant difference in the present value of the market with these best- and worst-case-scenarios. The final decision of launching the product is made by management, and thus their attitude towards risk becomes a major factor.

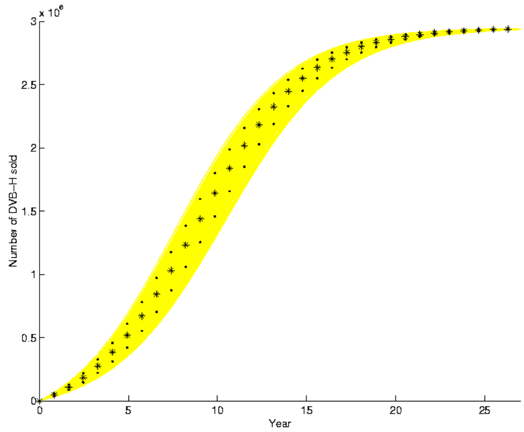
6.1 Sensitivity Analysis and some Qualitative Considerations

The sensitivity of the Bass model to noise in the parameters can be investigated by running simulations while holding some parameters constant and letting the others fluctuate.

The parameters and their interpretations were defined in sections 3 and 4. The parameter p was named by Bass as the coefficient of innovation, and its interpretation



(a)



(b)

Figure 9: Simulation results while (a) holding p constant (b) holding q and m constant.

is that it represents those people who are influenced by mass media. Parameter q is called the coefficient of imitation and it represents that part of the population that are influenced by the word of mouth effect. Finally, the parameter m defines the saturation level of the market.

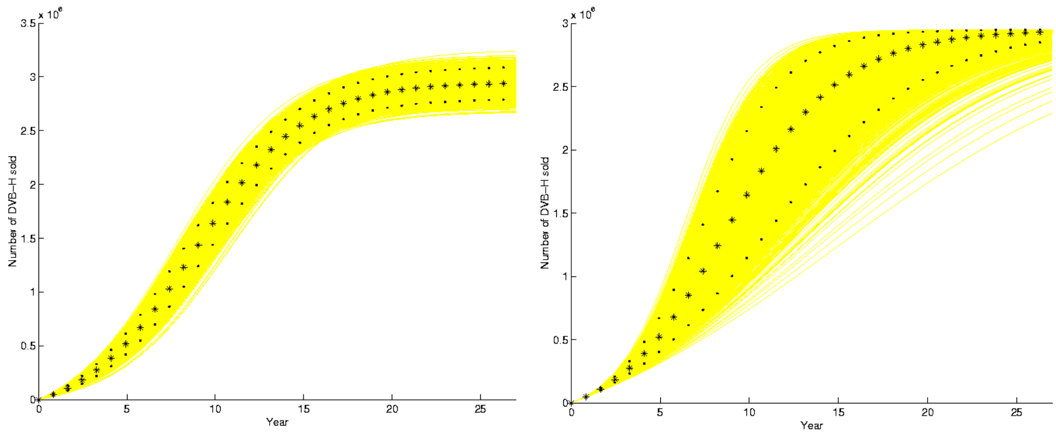
Figure 9(a) shows the simulation results for holding parameter p constant while q and m have uncertainty in them and 9(b) shows the simulation results while only p has noise.

Comparing figures 9(a) and 9(b) with one another, it is noticeable that the fluctuations in the parameter p have effect in the reliability of the results especially in the beginning of the diffusion curve. Reducing the noise in p, does not however significantly improve the reliability of the curve.

Figure 10(a) shows the simulation results for holding parameter q constant while p and m have uncertainty in them and 10(b) shows the simulation results while only q has noise.

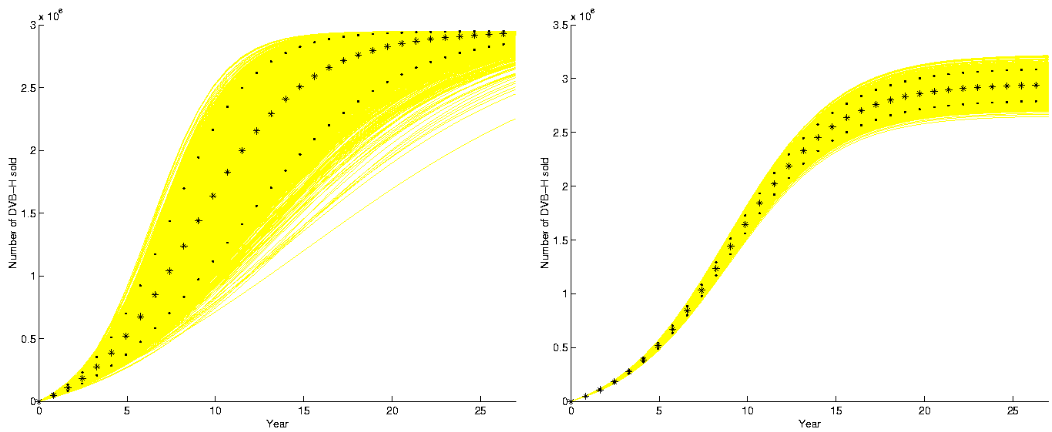
From figure 10 it is obvious that the uncertainty in parameter q is major factor on how wide the confidence level of the sold DVB-H equipment is. While figure 10(a) has a 95% confidence level which is quite narrow, figure 10(b) has a confidence level almost as wide as the original results.

Figure 11(a) shows the simulation results for holding parameter m constant while p and q have uncertainty in them and 11(b) shows the simulation results while only m has noise.



(a) (b)

Figure 10: Simulation results while (a) holding q constant (b) holding p and m constant.



(a) (b)

Figure 11: Simulation results while (a) holding m constant (b) holding p and q constant.

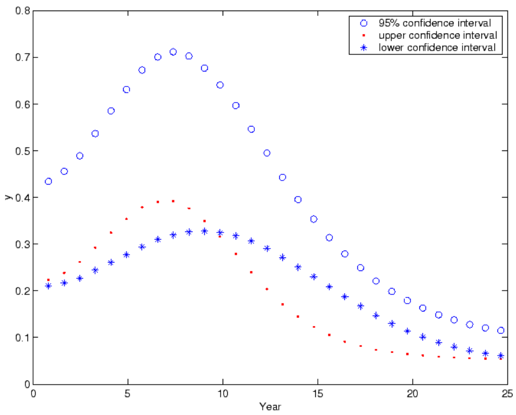


Figure 12: Development of the proportion between the confidence intervals and the forecast.

Holding m constant has the obvious results that it sets an upper limit to the saturation level. Thus, the only thing changing is the time of reaching the saturation point. From figure 11(a) it can be seen that the time of saturation can in extreme cases shift with over ten years. Considering the technological advances that can be made within such a time-frame, the need for exact knowledge of m can be questioned, because the effect of the other parameters seem to be dominating the diffusion curve. This, of course, applies only when the estimate for m is somehow reliable. When only m is uncertain, the forecast appears to be quite reliable in the beginning of the diffusion.

The development of the proportion between the different confidence intervals of the forecast and the forecast is presented in figure 12. The plotted quantities in the figure are the difference between the upper limit and the lower limit of the 95 % confidence interval divided by the forecast, the difference between the upper limit of the confidence interval and the mean of the simulation results divided by the forecast, and the difference between the lower limit and the forecast divided by the forecast.

Figure 12 gives another way of examining the effect of noise on the results. This way is to compare the proportion of the difference between the lower confidence level of a forecast to the forecast. This proportion should give an idea of the relative negative uncertainty connected to a forecast. Table 2 shows the mean and standard deviation for this proportion in the original and the sensitivity simulations.

The real effect of removing the uncertainty involved with a parameter can now be tested with a t-test or analysis of variance. In the analysis of variance, we do not take the beginning of the diffusion into account, because this proportion is zero

Table 2: The proportion between a lower confidence level and the mean of a forecast in the simulation.

Proportion	Simulation 1	p constant	q constant	m constant
$\bar{x}$	0.2000	0.1767	0.1033	0.1931
s_x	0.0978	0.0924	0.0607	0.1022
Proportion	p and q constant	p and m constant	q and m constant	
$\bar{x}$	0.0508	0.1676	0.0790	
s_x	9.1E-17	0.0978	0.0764	

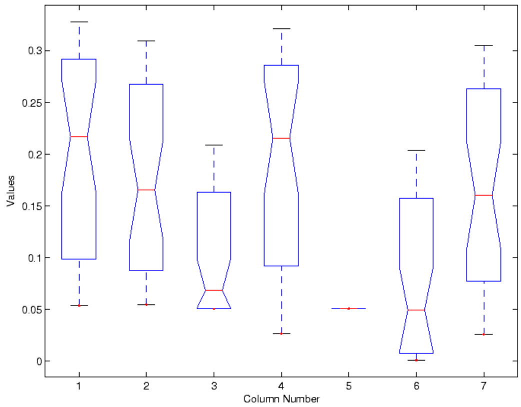


Figure 13: Graphical results of the analysis of variance. The order of columns in figure is the same as in table 2.

to all simulations (to be more precise, the proportion is not defined in this case, because we have $\bar{x} = 0$, $s_x = 0$ and the quantity $\frac{s_x}{\bar{x}}$ is not defined).

A one-way analysis of variance done with all the permutations in Table 2 gives results which are shown graphically in figure 13 and in table 3.

The so called box-plot in figure 13 shows the variance within a group for each simulation. The box shows the median and the upper and lower quartiles of the group. The whiskers show the maximum and minimum values within each group. From table 3 we get the P-value for the analysis of variance, which in this case is $P = 1.1$E-16. Statistically speaking this means that it is extremely unlikely

Table 3: Results of the analysis of variance.

Source	SS	df	MS	F	Prob ¿ F
Columns	0.7106	6	0.11843	17.41	1.11022e-016
Error	1.524	224	0.0068		
Total	2.23459	230			

that there is no difference among the groups. This is not surprising, because the deviation reduction is visible comparing figures 9(a) and 10(a).

From figure 13 other observations can also be made. The proportion seems to be much smaller in columns 3, 5 and 7. These columns represent the cases where parameter q has no related uncertainty. Furthermore, column 5, where the lower confidence bound is the closest to the forecast, is the case where only parameter m fluctuates. On the other hand the four remaining simulations seem to have almost equal means and quartiles. This indicates that the parameter q has an important role in the reliability of the diffusion.

The next analysis of variance can be done with the original simulation, simulation with p constant, simulation with m constant and simulation where m and p are both held constant. For this test the result is $P = 0.5168$, which indicates that there is no statistical difference between these groups. This result gives more elements towards deducting that the parameter which has the biggest effect in the wideness of the forecast is q. This conclusion can be based on the grounds that in all groups tested there was noise in the parameter q. Because the there is no difference between the groups, the noise of q must be dominating the diffusion equation.

What qualitative conclusions can be made from these results? Firstly, the word of mouth effect is crucial in the rate of diffusion. Things which form a customer's point of view seem to be shortcomings of the product, will most likely have a serious effect on the rate of diffusion. The technology of the end user equipment will develop in time with successive generations of products, which will deal with the problems associated to some aspects of the end user experience. Thus, technological problems that lower the rate of diffusion are only temporary. Easiness of use, availability and the usefulness of services on the other hand are things that should be considered carefully. If these factors are not suitable or interesting enough, the whole diffusion process might stop before it even begins.

The parameter m seems to have only little effect on the rate of diffusion. Still, this parameter should not be overlooked, because it is the only thing that regulates how big a success a product really will become. In other words; m does not effect the speed, but rather decides the level of the diffusion. Parameter p is has most of its effect in the very beginning of the diffusion. This parameter can probably be increased with advertising.

As another purely qualitative subject one should bear in mind that the entire forecast is based on the assumptions that underlie in the Bass model. Thus merely choosing the model as a starting point for such a forecast represents a significant and defining assumption. Whether or not it is justified is a very difficult question; its vastly spread use in literature, however, suggests that it is at least on widely accepted grounds. Choosing this model fixes irreversibly, for example, the fact that the product is guaranteed to successfully reach its maximum adoption level defined by the parameter m. Thus this parameter plays important role in the entire forecast and failure to estimate it and its deviation properties inevitably leads to biased forecast.

A final notion on the sensitivity analysis is that only three parameters with relatively moderate noise result in a large range of possible outcomes. Will improvement in the model, such as taking pricing and advertising effort explicitly into account, actually improve the forecast, or only broaden the confidence levels?

7 Recommendations and future work

The convergence of digital content formats, networks and connections using IP, and portable devices with wireless communications capabilities are disruptive technologies jointly fuelling a new business opportunity. DVB-H is a possible solution. This research paper provides a forecast for the market demand of DVB-H services in Finland. The forecast is based on a diffusion model and the parameters are derived from analogous products since no data are available.

The simulation results show that the cumulative adoption level will reach 10 % on the average within the first three years. 50 % adoption level will be achieved in nine years and 90 % adoption level in just over 16 years.

According to the forecast, the point of inflexion will occur after eight years from launch of the product. The subscriptions during this year will be approximately 250,000 units.

The confidence interval is also at its widest at the point of inflexion, when the proportional difference between the cumulated average and the 2.5 % percentile is almost 35 % of the predicted sales, or 400,000 units. The absolute difference of the cumulated median and the 2.5 % percentile is biggest around the year 12, reaching a figure of 600,000 units.

Although it is assumed that there is no uncertainty in time, the simulation results can be analysed within the time-frame. From Figure 8 it can be estimated that in terms of the 95 % confidence interval, the first 500,000 units are sold somewhere between four and seven years from the launch of the product. Further on, the time frame only expands so that with one million units the time frame is three years, reaching from 6 to 9 years. For 1.5 million units, the time gap is 5.5 years and 6 years for two million products sold.

The performed sensitivity analysis shows that the diffusion model is most sensitive to perturbations in the coefficient of imitation, q. The coefficient of imitation estimated from our analogies has the largest proportional error, because the values of q for Walkman and DIRECTV differ so much from one another. This also raises the question how well do these analogies present the qualities that are of importance in the case of DVB-H. It is necessary to consider also the alternative that one or both of the analogies fail to capture the real diffusion rate. Moreover, the data for Walkman is international, which means that we must assume that the rate of diffusion is independent of the geographical location. Literature written of this matter states that this assumption is not valid.

In the simulation, the saturation level parameter m is time invariant. However, the present plan is to build up coverage while services are already available to customers. Because saturation level depends heavily on coverage, it would be more realistic to represent m as a dynamic variable. Thus it is important to update the parameter estimates as soon as there is market survey data available.

Service adoption modelling based on diffusion models and supporting data of previous analogies will give reasonable estimates also for new concepts where no market data is not yet available. In case of DVB-H there are so many unknowns that a qualitative analysis was carried out in parallel to the quantitative forecast in order to identify the factors which are most likely to impact the accuracy of the forecast. In the scope of this study is was not possible to model all the qualitative service adoption factors of the analogies. Such a broad comparison has not been done in literature either.

Based on the qualitative analysis at least following factors will impact the service adoption and if not handled properly may become real show stoppers of the planned service.

1. Pricing of the service and the end user device. Pricing of the service and end user devices must have comparable value proposition to the similar services available at the same time frame. Value of mobility may offer some possibility to price premium.

2. Lack of proven use case, e.g. normal TV application. Analogies used in this study both have an existing use case as a baseline. Therefore the quantitative analysis is heavily relying on the proven use case approach. But also the qualitative analysis indicates that much more additional effort is needed in promoting the completely new use cases if the service adoption is to be based on new services only.

3. Low coverage of the service. The quantitative analysis assumes full coverage of the population from the beginning. This is virtually achievable if

cellular service and local memory is used to compensate the missing DVB-H coverage in the early days of the service and also later to provide cost efficient way to fill the gaps in the service coverage.

4. Value system complexities. Value system of IP Data case is challenging because it forces two existing value systems to fully integrate. Clear responsibilities and possibility to gain profits is an essential requirement.

5. Low number of interesting new services with good value for money. DVB-H system is not a full competitor to any of the existing services. Therefore there must be reasonable set of new and innovative services dedicated to the DVB-H system only.

6. Poor Usability of the end user products. End users' experience of the portable device is always a challenge. DVB-H especially include challenges in the field of audio visual experience. Good voice and video quality can be done but this may increase device cost and anyway will cause higher power consumption. If adequate technologies are not available before serious service launch there is a serious risk for total failure of service adoption.

7. Possibility to test the service. Along with the proven use case (point #2) the possibility to test the service before full commitment is important to reduce the end user's risk.

8. Wide adoption of IPDC concept. The same technology must be implemented also outside of Finland in order to bring the prices of terminals and services down as well as to increase the overall awareness of the consumers. Without at least Pan-European market the service adoption in Finland alone is not seen realistic.

It should be evident from these results that the uncertainty accompanying the forecast is vast. Therefore, one should not hold the given forecast as the ultimate truth, but more as a kind of an educated guess.

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Appendix

1 Cumulative Subscriptions of DIRECTV

A section from data.m [2, 14]

```
dirdate=['31-Dec-1994'; '31-Dec-1995'; '31-Dec-1996';
    '31-Dec-1997'; '31-Dec-1998'; '31-Dec-1999'; '31-Dec-2000'
    '31-Dec-2001'; '31-Jan-2002'; '28-Feb-2002';
 '31-Mar-2002'; '30-Apr-2002'; '31-May-2002'; '30-Jun-2002';
 '31-Jul-2002'; '31-Aug-2002'; '30-Sep-2002'; '31-Oct-2002';
 '30-Nov-2002'; '31-Dec-2002'];
global directdate;
directdate=datenum(dirdate);
global directcum;
directcum=1E6*[0.32 1.2 2.3 3.301 4.458 6.679 9.554 10.218
10.350 10.4 10.56 10.6 10.7 10.775 10.843 10.913
10.92 11.050 11.160 11.181]';
```

2 Cumulative Sales of Walkman

A section from data.m [17]

```
sonywmdate=['31-Dec-1979'; '31-Dec-1980'; '31-Dec-1981';
'31-Dec-1982'; '31-Dec-1983'; '31-Dec-1984';
'31-Dec-1985'; '31-Dec-1986'; '31-Dec-1987'; '31-Dec-1988';
'31-Dec-1989'; '31-Dec-1990'; '31-Dec-1991'; '31-Dec-1992';
'31-Dec-1993'; '31-Dec-1994'; '31-Dec-1995'; '31-Dec-1996';
'31-Dec-1997'; '31-Dec-1998'];
global wmdate;
```

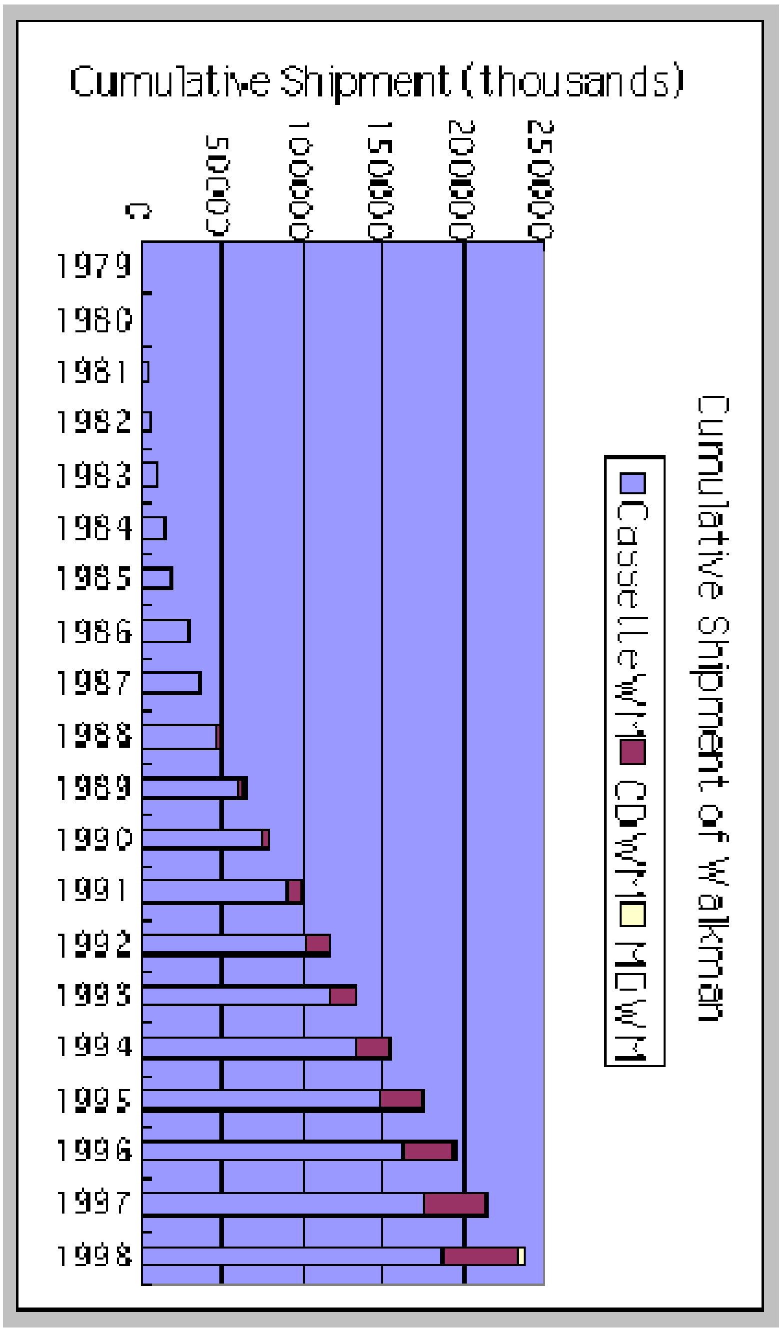

Figure 14: Cumulative worldwide sales of Walkman [17].

```
wmdate=datenum(sonywmdate);
global wmcum;
wmcum=1/12*50000*1000*[0 0 1 1 2 3 4 6.5 8.5 11 14 18 21.5
25 27 30.5 34.5 38 41 43]';
```

3 Matlab code for estimating parameters

bass.m

```
%returns the cumulative value [0, 1] of the Bass function for
%the given t>0 and p=param(1), q=param(2)
function answer=bass(t,param)
answer=(1-exp(-(param(1)+param(2))*t))./
(param(2)/param(1)*exp(-(param(1)+param(2))*t)+1);
```

residual.m

```
%Returns the residual squared sum \sum (y_i-\hat{y}_i)ˆ2
function answer=residual(param, t, y, t0, m)
yest=m*bass(t-t0, param);
sumsq=0;
for (i=1:length(y))
    sumsq = sumsq + (y(i)-yest(i))*(y(i)-yest(i));
end
answer=sumsq;
```

etsidirect.m

```
%Fits the Bass model to DIRECTV data in the least squares sense and
%returns the optimum parameters p=answ(1), q=answ(2)
function answ=etsidirect(param)
global directdate;
global directcum;
global mdirect;
answ=fminsearch(@residual,param, [], directdate, directcum,
datenum('31-Dec-1994'), mdirect);
```

residualm.m

```
%Returns the residual squared sum \sum (y_i - \hat{y}_i)ˆ2
function answer=residualm(param, t, y, t0)
yest=param(3)*bass(t-t0, param(1:2));
sumsq=0;
for (i=1:length(y))
    sumsq = sumsq + (y(i)-yest(i))*(y(i)-yest(i));
end
answer=sumsq;
```

etsiwm.m

```
%Fits the Bass model to the Walkman data in the least squares sense
%and returns p=answ(1), q=answ(2) and m=answ(3)
function answ=etsiwm(param)
global wmdate;
global wmcum;
answ=fminsearch(@residualm,param, [], wmdate, wmcum,
datenum('31-Dec-1979'));
```